L6- Electrical Measurements
Analog and Digital Measurements
(EE 300/EE307)

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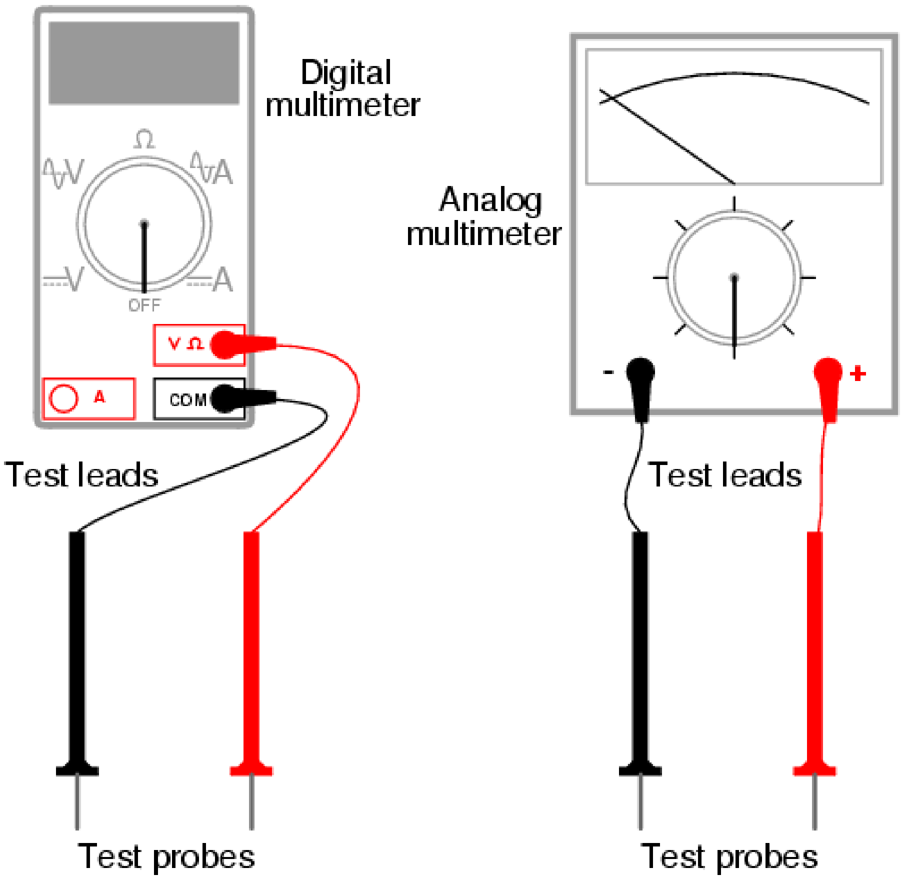
Measuring Electrical Quantity

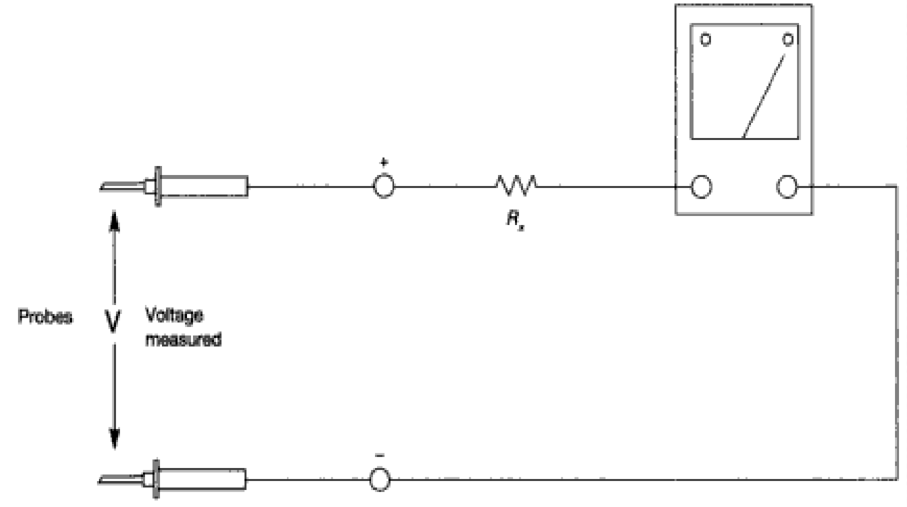
- voltage measurement technique
- current measurement technique
- resistance measurement technique
- capacitor measurement technique
- inductor measurement technique
- oscilloscope
- waveform measurement



Voltage Measurement Technique-1

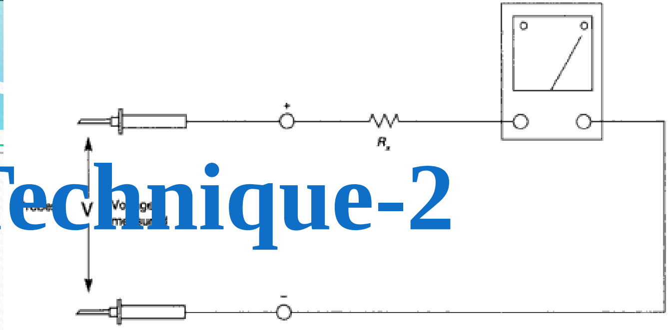
- Voltage can be measured using Voltmeter or Oscilloscope
- Voltmeter
  - instrument used for measuring the electrical potential difference between two points in an electric circuit

- The voltage can be measured by passing a current through a resistance; therefore, a voltmeter can be seen as a very high resistance ammeter connection in parallel with the circuit being measured



- should have high resistance compared to the circuit being measured to minimized the loading effect

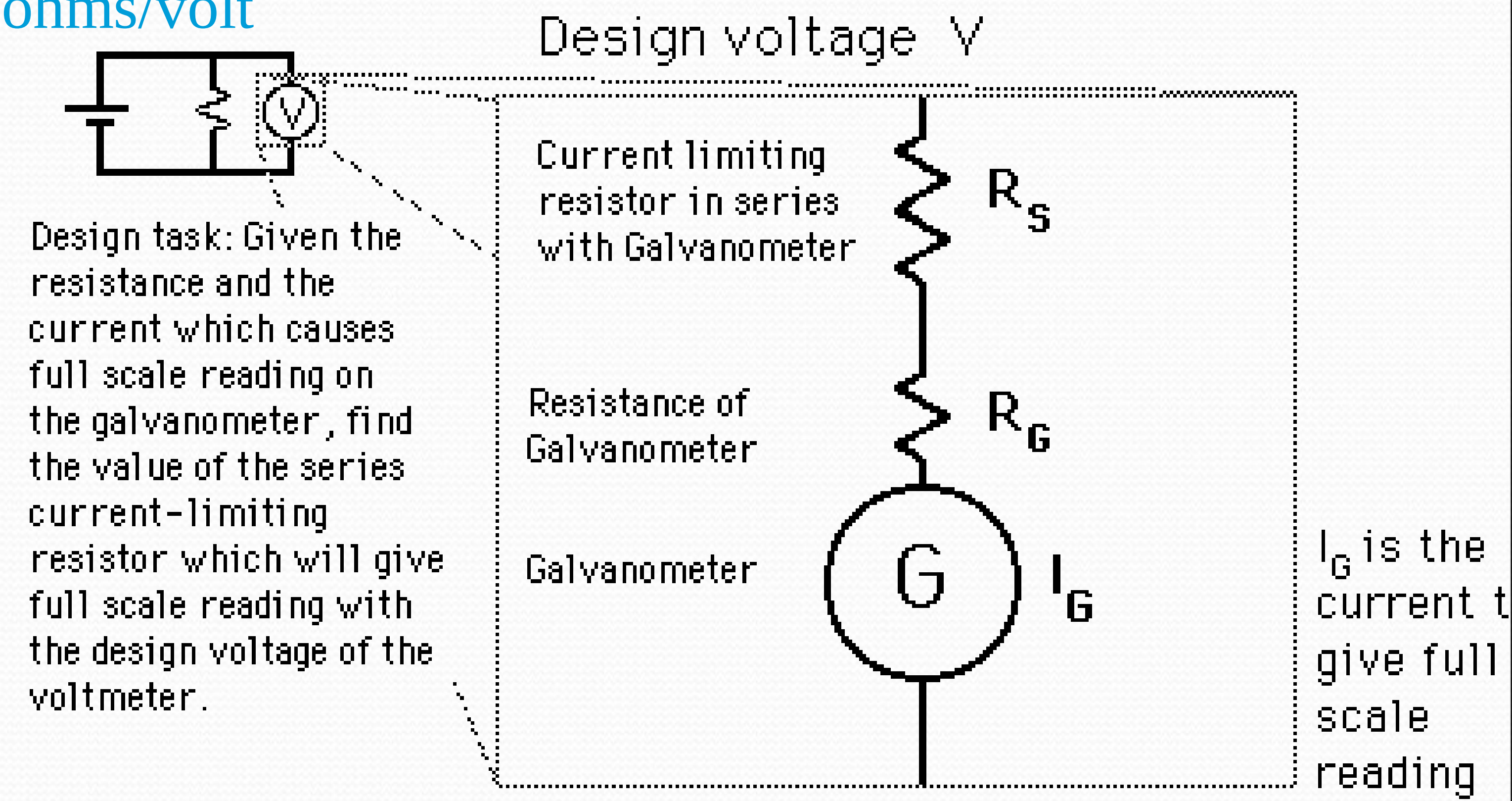
Voltage Measurement Technique-2



- Since resistance of a meter movement is constant, voltmeter can be made from a current-sensitive meter movement (galvanometer),

using range of resistors & an appropriate scale sensitivity, S is expressed in ohms/volt

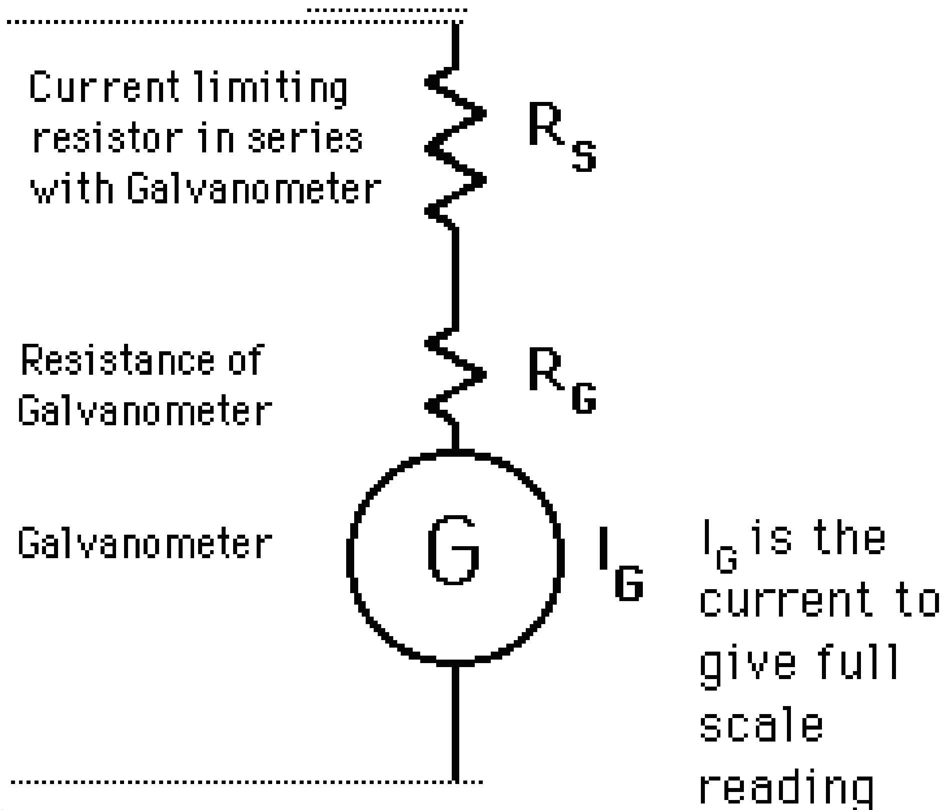
Design Voltmeter :-



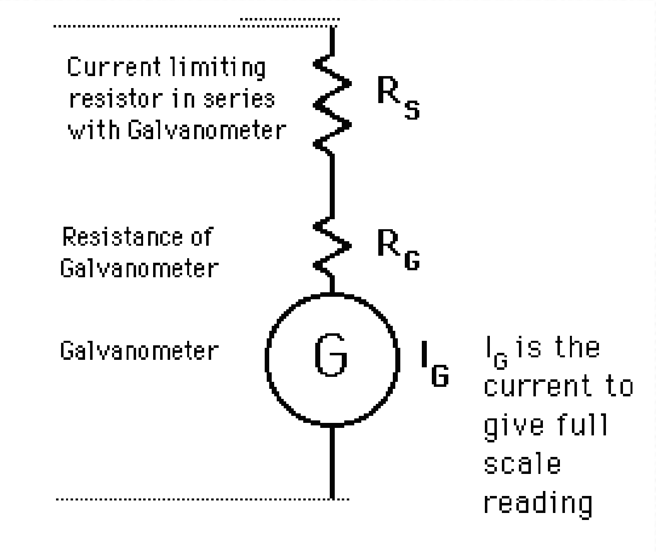
Voltage Measurement Technique-3

- voltmeters, as well as ammeters and ohmmeters, are designed with the use of a sensitive current detector, galvanometer

- voltmeter is placed in parallel with a circuit element to measure the voltage drop across it and must be designed to draw very little current from the circuit so that it does not appreciably change the circuit it is measuring



Example-1



If a galvanometer with R_G = 1000 Ω , I_G = 3 mA is used to design a voltmeter for a full scale voltage V = 30 volts, the required series resistor is given by

$$R_S = \frac{V_{design}}{I_G} - R_G = 9000 \ \Omega$$

Example-2

- The coil of a moving coil voltmeter is 4 cm long and 3 cm wide and has 100 turns on it. The control spring exerts a torque of 2.4×10^{-4} N-m when the deflection is 100 divisions on the full scale. If the flux density of the magnetic filed in the air-gap is 0.1 Wb/m^2, estimate the resistance that must be put in series with the coil to give one volt per division. The resistance of the voltmeter coil may be neglected.

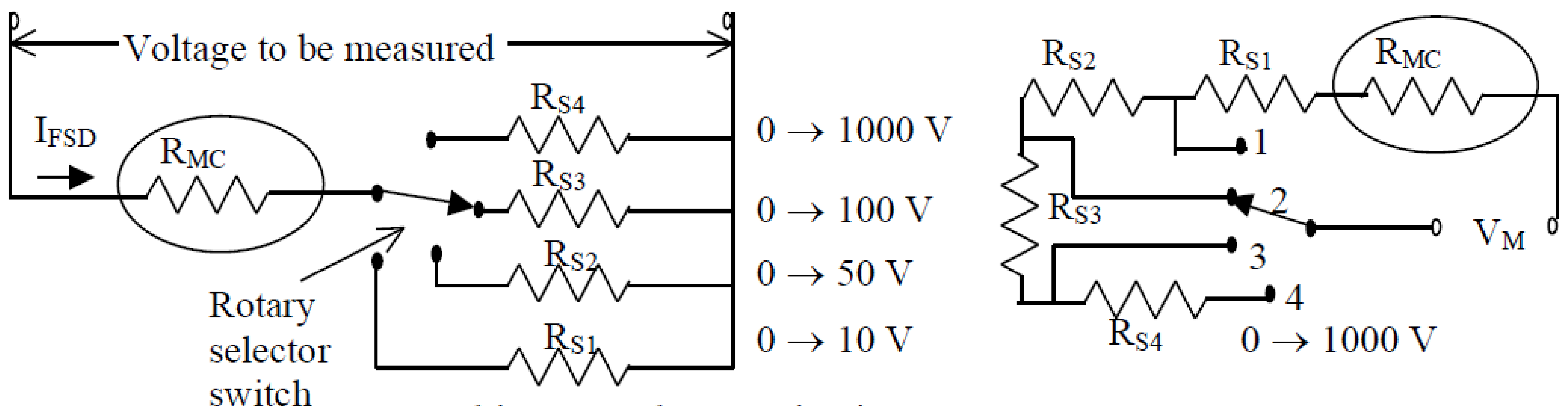
Solution

- $T_{EM} = T_{SP} = NBAI \Rightarrow 2.4 \text{ x } 10^{-4} = 100 \text{ x } 0.1 \text{ x } 12 \text{ x } 10^{-4}\ x\ \ I_G$
- $\Rightarrow I_G = 20$ mA. Therefore, current per division is 0.2 mA.
- Assuming that R_G is negligibly small compared to R_S : $R_S = 5\ \text{k}\Omega$

Example-3

- A moving coil instrument gives full-scale deflection of 10 mA when the potential difference across its terminals is 100 mV. Calculate:
- The shunt resistance for a full scale corresponding to 100 mA;

$$R_S = 100 / 90 = 1.11\ \Omega$$



Multi-range voltmeter circuit
Parallel connection

Multi-range voltmeter circuit
Series connection

Example-3, Cont.

- The resistance for full scale reading with 1000 V;

  $R_G = 100\ /10 = 10\ \Omega$; $R_S + R_G = (1000\ /\ 10)\ \mathrm{k}\Omega = 100\ \mathrm{k}\Omega$

  yielding $R_S = 100\ \mathrm{k}\Omega$ (R_G is negligible)

- The power dissipated by the coil and by the external resistance in each case.

  Power dissipated by the coil, $P_C = I_M^2\ x\ R_G = 1$ mW;

  $P_S = V_M^2/\ R_S = 9$ mW

  $P_S = V_M^2/R_S = 10$ W.

Example-4

- A multi-range DC voltmeter is designed using a moving coil with full-scale deflection current 10 mA and coil resistance 50 Ω. Ranges available: 0 – 10V, 0 – 50V, 0 – 100V, 0 - 1000V. Determine the multiplier resistors and input resistance of the meter using:
  - A) Conventional connection
  - B) Modified connection

Solution

- In conventional connection, resistors are selected one-by-one to satisfy,
- $V_M = I_G\,(RG + RS) = VG + I_G R_S$ where V_M is the full-scale voltage of the selected range. V_G = (10mA)(50Ω) = 0.5V.

Example-4 Cont.

- Hence, $R_S = (V_M – 0.5)/10\ k\Omega$. Meter resistance seen between the input terminals is $R_M = R_G + R_S$
- Range 1 (0 – 10V): $R_{S1} = 9.5/10 = 0.95\ k\Omega = 950\ \Omega$;

  $R_{M1} = 950\ \Omega + 50\ \Omega = 1000\ \Omega$
- Range 2 (0 – 50V): $R_{S2} = 49.5/10 = 4.95\ k\Omega$;

  $R_{M2} = 4.95\ k\Omega + 0.05\ k\Omega = 5\ k\Omega$
- Range 3 (0 – 100V): $R_{S3} = 99.5/10 = 9.95\ k\Omega$;

  $R_{M3} = 9.95\ k\Omega + 0.05\ k\Omega = 10\ k\Omega$
- Range 4 (0 – 1000V): $R_{S4} = 999.5/10 = 99.95\ k\Omega$;

  $R_{M4} = 99.95\ k\Omega + 0.05\ k\Omega = 100\ k\Omega$

Example-4 Cont.

- For the alternative modified arrangement, the resistor for the lowest range is determined and others calculated as added to the total of the previous value. The total resistance seen from the input in all ranges will be the same as those in the previous case. Resistors between stages can be computed as
- $R_{Sn} = R_{Mn} – R_{M\,(n\text{-}1)}$
- • Range 1 (0 – 10V): R_{M1} = 1000 Ω; R_{S1} = 1000 Ω - 50 Ω = 950 Ω
- • Range 2 (0 – 50V): R_{M2} = 5 kΩ; R_{S2} = 5 kΩ - 1 kΩ = 4 kΩ;
- • Range 3 (0 – 100V): R_{M3} = 10 kΩ; R_{S3} == 10 kΩ - 5 kΩ = 5 kΩ;
- • Range 4 (0 – 1000V): R_{M4} = 100 kΩ; R_{S4} = 100 kΩ - 10 kΩ = 90 kΩ;

Example-5

A basic D'Arsonval meter movement with an internal resistance $R_G = 100\ \Omega$, full scale current $I_G = 1mA$, is to be converted into a multi-range DC voltmeter with ranges 0-10 V, 0-50 V, 0-250 V and 0-500V.

Find the values of multiplier resistors using the potential divider arrangement.

- Four resistors R_{S1} -R_{S4} are added in series with R_G.
- In the first range (0-10 V) only R_{S1} is used and the maximum voltage drop on R_{S1} is 10-0.1=9.9V.

  Thus, R_{S1} = 9.9V/1mA = 9.9 kΩ

- In the 2nd range (0-50 V) R_{S1} +R_{S2} is used and the maximum voltage drop on R_{S2} is 50-10= 40 V.

  Thus, R_{S2} = 40V/1mA = 40 kΩ

Example-5 Cont.

- In the 3rd range (0-250 V) R_{S1} + R_{S2} +*RS3* is used and the maximum voltage drop on *RS3* is 250-50=200 V.

  Thus, R_{S3} = 200V/1mA = 200 kΩ

- In the 4th range (0-500 V) R_{S1} + R_{S2} + R_{S3}+ R_{S4} is used and the maximum voltage drop on *RS4* is 500-250= 250 V.

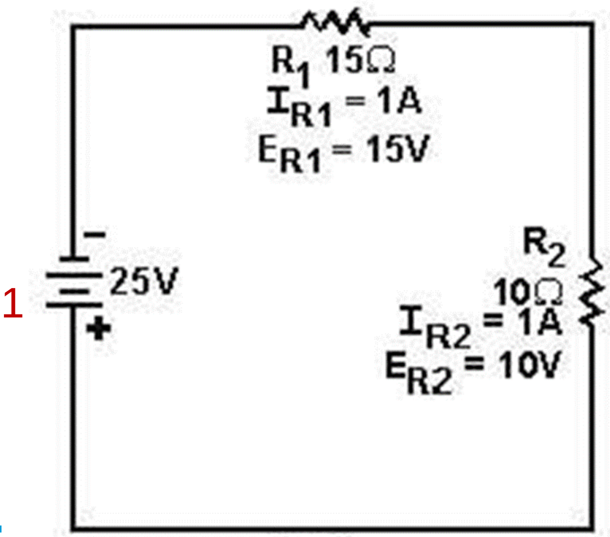
  Thus, R_{S4} = 250V/1mA = 250 kΩ

Voltmeter loading effect

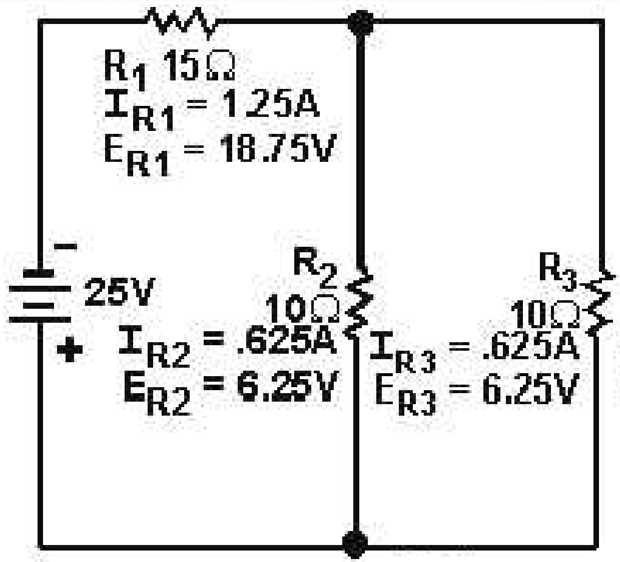
In figure (A), a series circuit is shown with R_1 equaling 15 ohms and R_2 equaling 10 ohms

The voltage across R_2 (E_{R2}) equals 10 volts.

If a meter (represented by R_3) with a resistance of 10 ohms is connected in parallel with R_2, as in figure (B), the combined resistance of R_2 and R_3 (R_N in-parallel) is equal to 5 ohms.



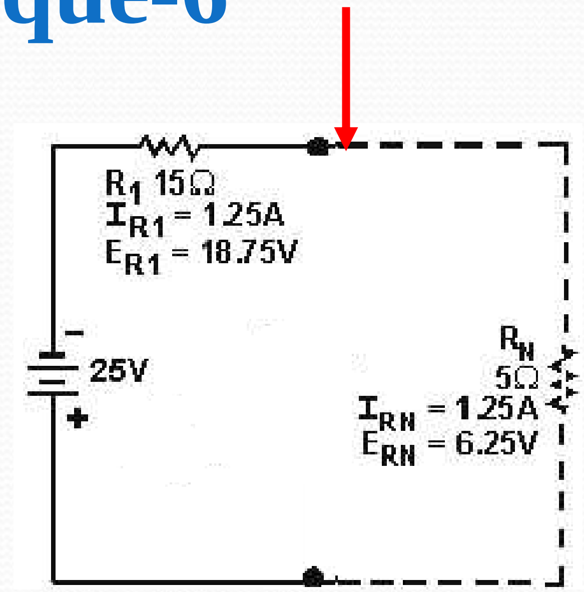
(A)



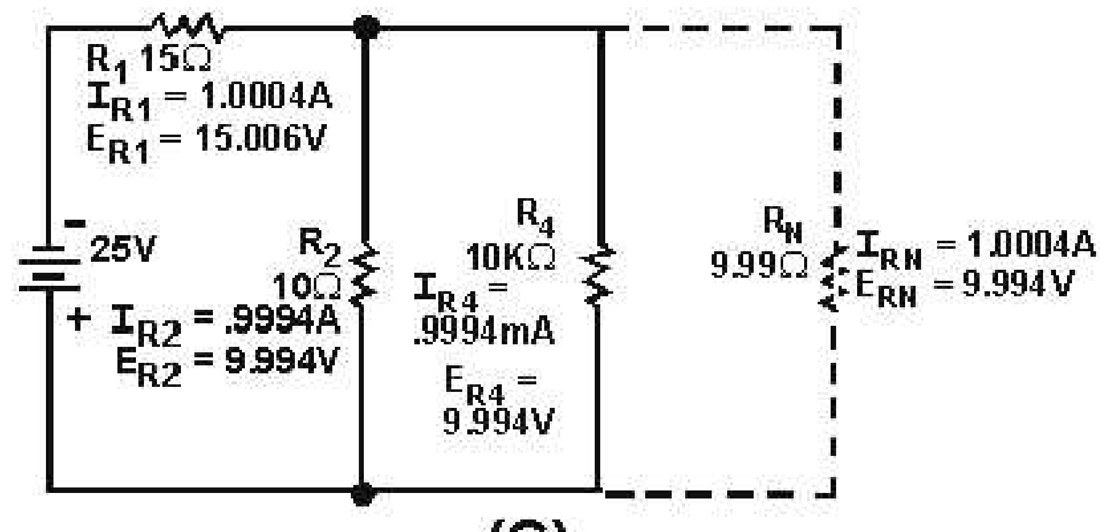
(B)

Voltage Measurement Technique-6

- The voltage across R_2 and R_3 is now 6.25 volts, and that is what the meter will indicate. Notice that the voltage across R_1 and the circuit current have both increased. The addition of the meter (R_3) has loaded the circuit.



- In figure (C), the low-resistance meter (R_3) is replaced by a higher resistance meter (R_4) with a resistance of 10 kilohms.

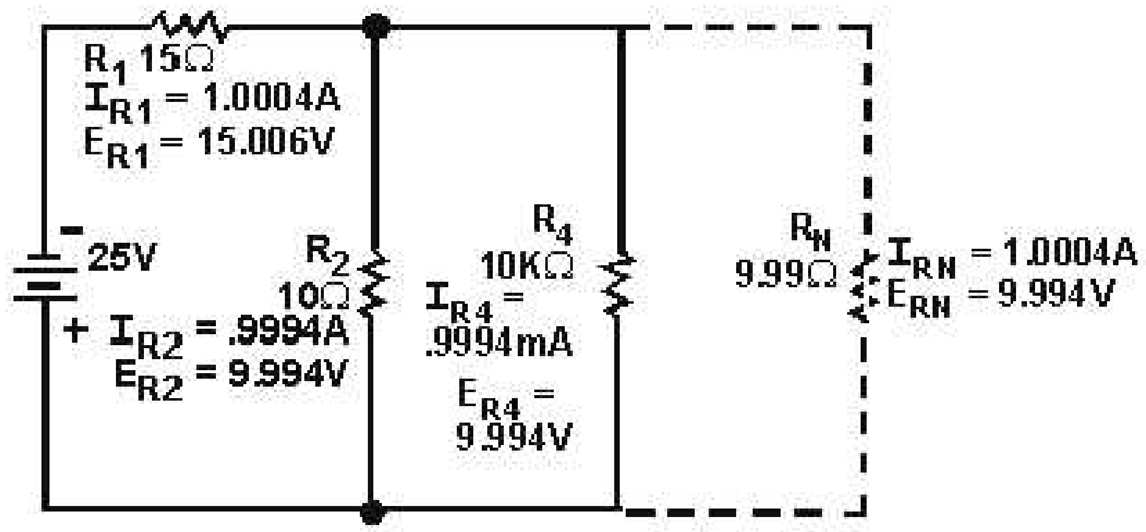


(C)

Voltage Measurement Technique-7

- The combined resistance of R_2 and R_4 (R_N) is equal to 9.99 ohms. The voltage across R_2 and R_4 is now 9.99 volts, the value that will be indicated on the meter. This is much closer to the voltage across R_2, with no meter (R_3 or R_4) in the circuit.

Notice that values in figure (C) are much closer to the values in
figure (A). The current (I_{R4}) through the meter (R_4) in figure (C) is also very small compared to the current (I_{R2}) through R_2



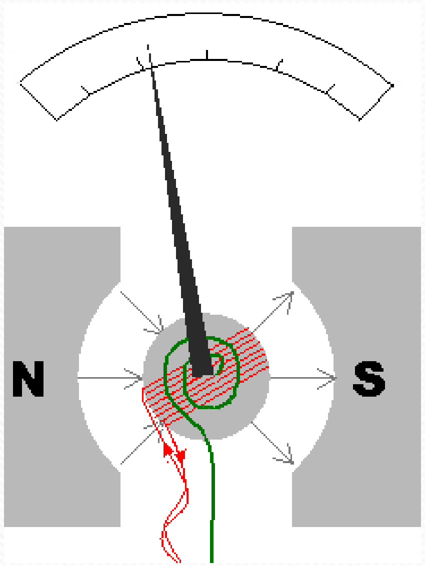
(C)

In figure (C) the meter (R_4) has much less effect on the circuit and does not load the circuit as much. Therefore, a voltmeter should have a high resistance compared to the circuit being measured, to minimize the loading effect.

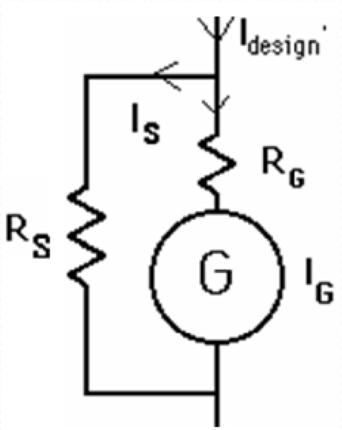
Current Measurement Technique-1

- Current can be measured using Ammeter or Oscilloscope

- ## Ammeter
  - The earliest design is the D'Arsonval galvanometer or moving coil ammeter
  - It uses magnetic deflection, where current passing through a coil causes the coil to move in a magnetic field.

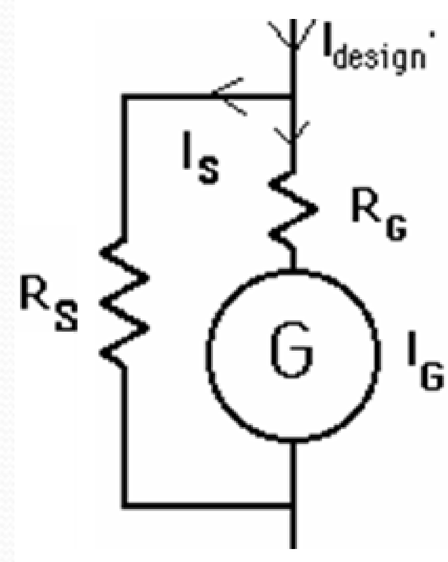


- **Model of MC based instrument**



Basic DC Ammeter (Ampermeter)

- The current capacity of the meter can be expended by adding a resistor in parallel with the meter coil.
- The input current is divided between the coil resistance R_{MC} and the parallel resistance R_{SH}.
- As the maximum input current IT flows in, the coil takes I_{FSD} and remaining (I_T - I_{FSD}) is taken by the shunt resistor.



- Voltage developed across the meter is

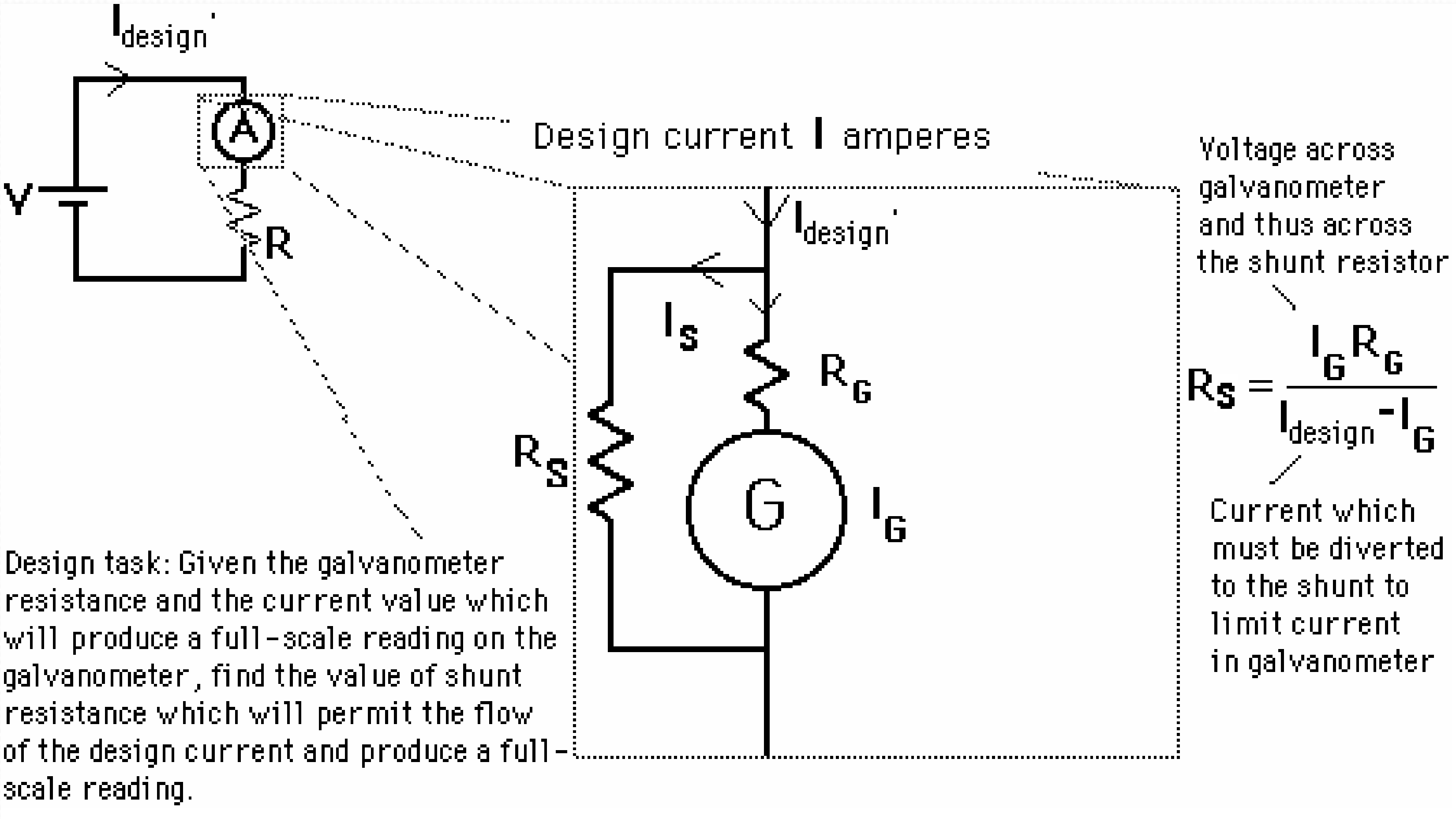
$$V_G = I_G R_G = (I_{design} - I_G) R_S = I_s R_s$$

The meter resistance R_M seen between the input terminals is

$$R_s = V_G / I_T = R_g // R_S$$

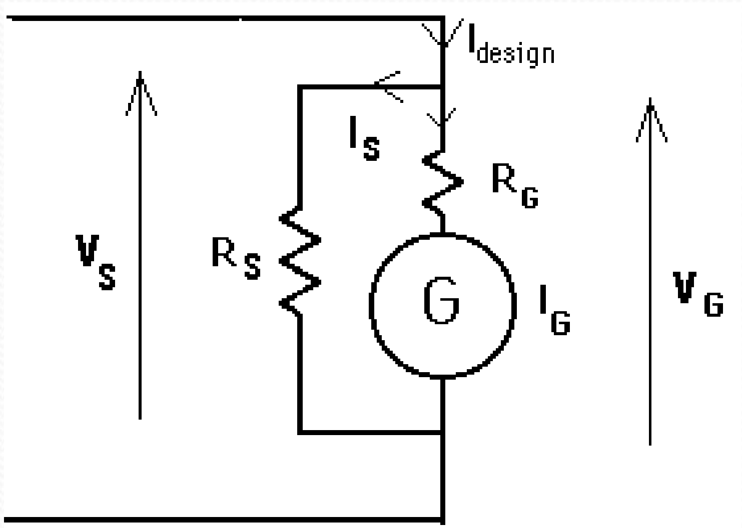
Current Measurement Technique-2

- Design Ammeter



Current Measurement Technique-3

- Design Ammeter: Analyse circuit
- $V_S = V_G$, $I_{design} = I_S + I_G$
- $V_S = I_S \times R_S$
- $V_G = I_G \times R_G$
- I_G, R_G, I_{design} will be specified



Example 6

If a galvanometer with $R_G =$ 1000 Ω , $I_G =$ 30 mA

is used to design an ammeter for a full scale current I = 10 amperes, the required shunt resistor is given by

$$R_S = \frac{I_G R_G}{I_{design} - I_G} = 3.00902708\text{ } \Omega$$

Example -7

- Calculate the multiplying power of a 200 Ω shunt resistance used with a galvanometer of 1000 Ω resistance. Determine the value of shunt resistance to give a multiplying factor of 50.

Solution

$$V_G = I_G R_G = (\mathrm{I}_{design} - I_G)\, R_S = I_s R_s$$

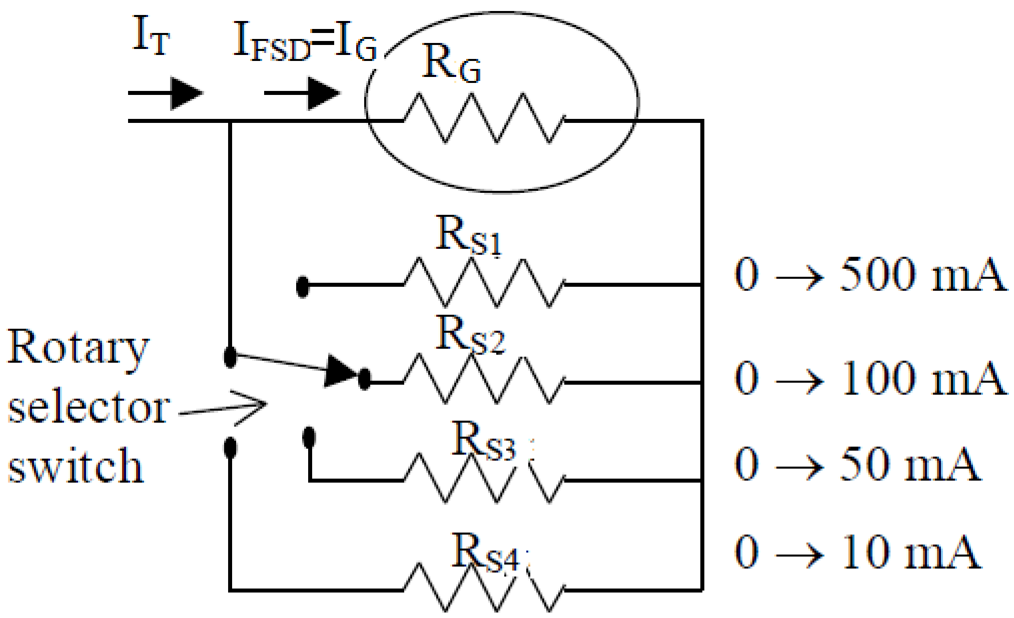
$$I_G \text{ x } 1000 = (I_T - I_G) \text{ x } 200 \longrightarrow I_T = 6 \, x \, I_G.$$

For $I_T = 50 \, x \, I_G$, $1000 \text{ x } I_G = (50\text{-}1) \text{ x } I_G \, x \, R_s$

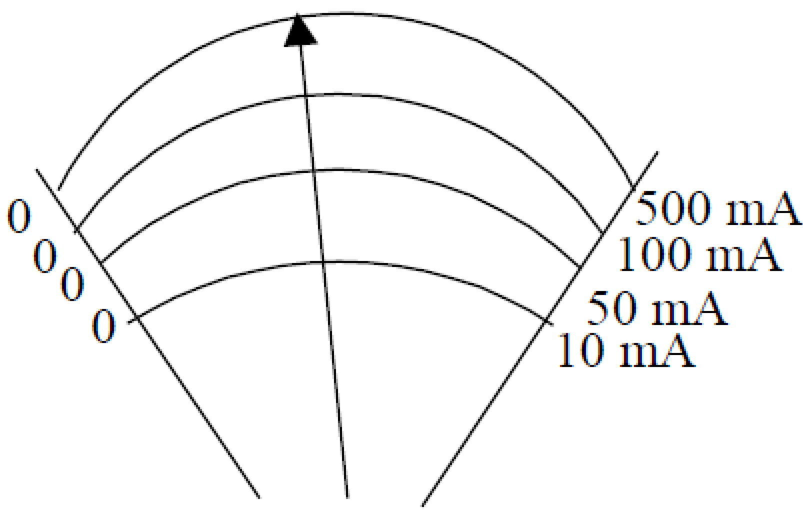
$$\longrightarrow R_{sh} = 1000/49 = 20.41\ \Omega$$

Example-8

- Design a multi-range DC ammeter using the basic movement with an internal resistance R_G= 50 Ω and full-scale deflection current I_G= I_{FSD}= 1 mA. The ranges required 0-10 mA, 0-50 mA, 0-100 mA and 0-500 mA as illustrated .



Multi-range ammeter circuit



Multi-range ammeter scale

Example-8, Cont.

Solution

$V_{MC} = I_{MC}\, x\, R_{MC} = 50 \text{ mV}$

- For range-1 (0-10 mA) $RSH1 = 50/9 = 5.56\ \Omega$
- For range-2 (0-50 mA) $RSH2 = 50/49 = 1.02\ \Omega$
- For range-3 (0-100 mA) $RSH3 = 50/99 = 0.505\ \Omega$
- For range-4 (0-500 mA) $RSH4 = 50/499 = 0.1\ \Omega$

Example 9

A moving coil has 100 turns, 5 cm^2 coil area, and air-gap magnetic flux density of 0.1 Tesla (Wb/m^2).The control spring exerts a torque of 5×10^{-6} N-m at the full-scale deflection of 90°. The potential difference across the coil terminals at the full-scale deflection is 100 mV. Using the above movement, design a multi-range DC ammeter with ranges 0-50 mA, 0-1 A and multi-range DC voltmeter with ranges 0-10 V and 0-200 V.

Solution

$I_G = T_{SP}/NBA$ = 1 mA, therefore $R_G = V_G / I_G = 100\ \Omega$

For ammeter ranges: R_{S1}= 100 mV/ (50-1) mA = 2.04 Ω

and R_{S2} = 100/999 = 0.1 Ω

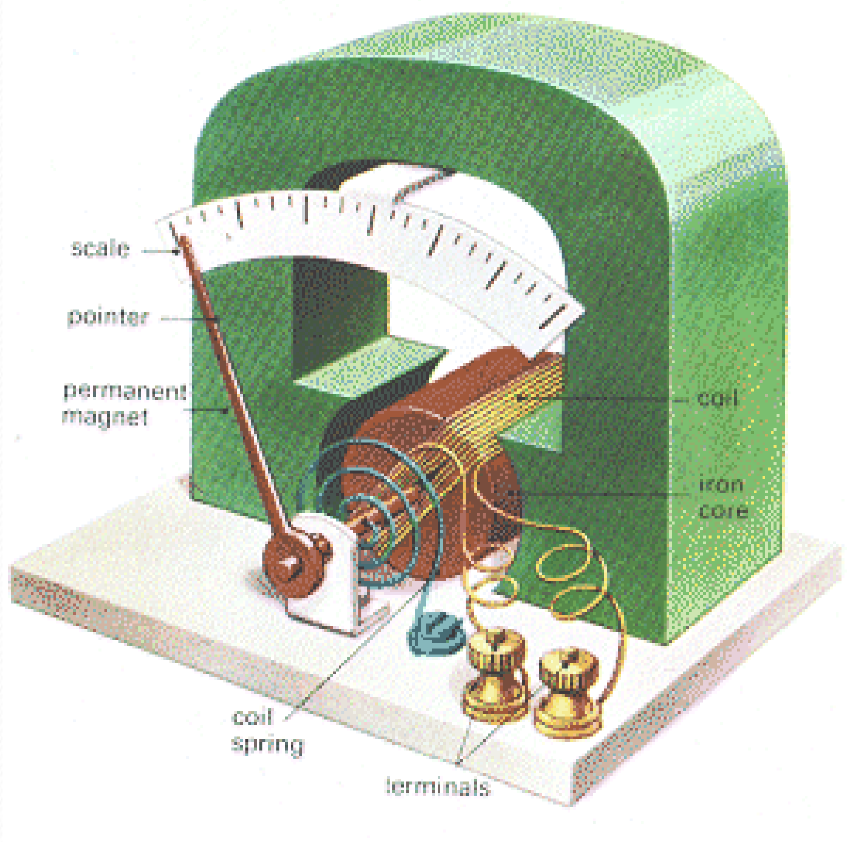
For voltmeter ranges: R_{S1} = (10-0.1)V/1mA = 9.9 kΩ

and R_{S2}= 199.9 kΩ

Current Measurement Technique-4

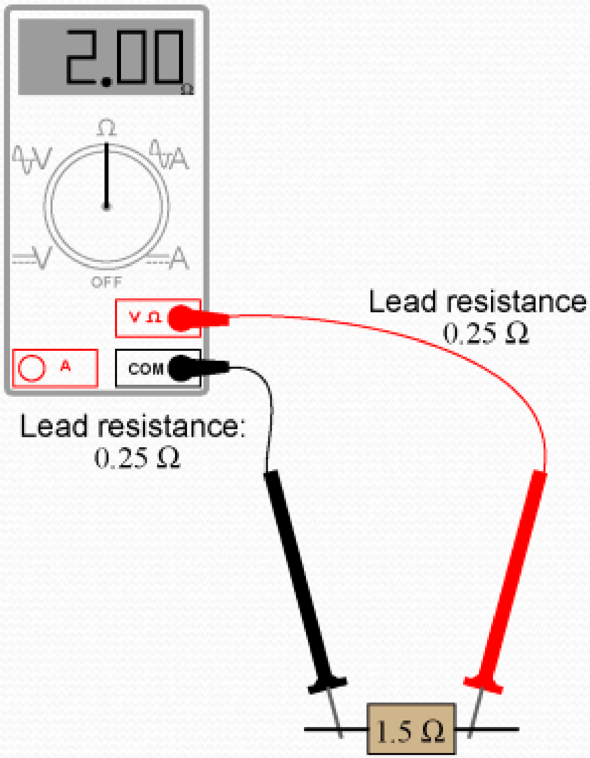
Ammeter: safety precautions

- always connect ammeter in series
- always start with highest range
- de-energize & discharge the circuit before connecting or disconnecting the ammeter
  - never use dc ammeter to measure ac current
  - observe/use correct polarities



Resistance Measurement Technique

- Resistance can be measured
- using:-
  - Voltmeter – Ammeter
  - Ohmmeter
  - Wheatstone bridge
  - Kelvin Bridge



Voltmeter – Ammeter

- voltmeter parallel with resistor
- ammeter series with resistor
- Resistance is obtained

by applying Ohm's Law:

- $R = V / I$

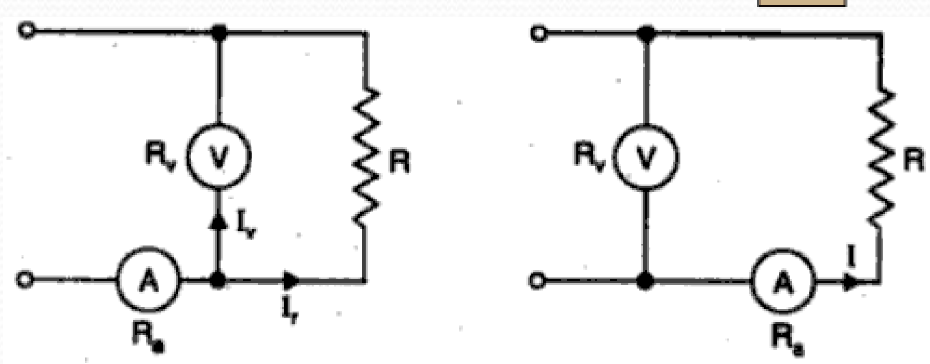


Fig. . Methods for measuring resistance.

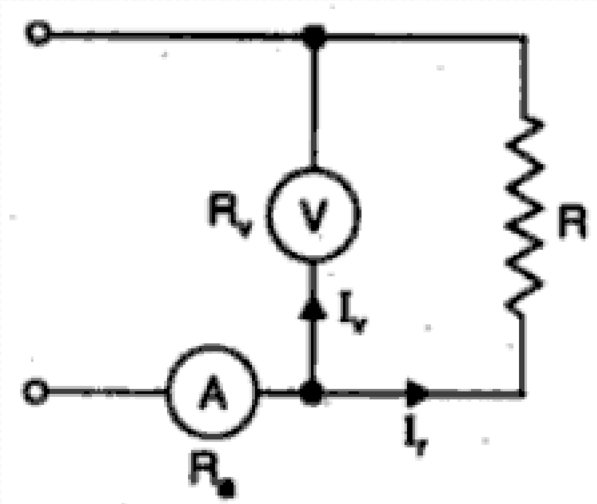
Voltmeter – Ammeter: 2nd configuration

1) $I = I_v + I_r$, $I = V/R_v + V/R$, $V/R = I - V/R_v$

$$R = V/(I - V/R_v)$$

If Rv very large ➔ $R = V/I$

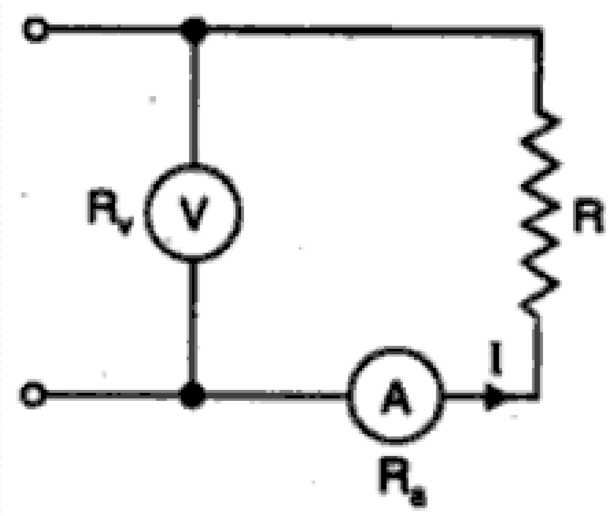
- R_a = resistance of the ammeter (very small)
- R_v = resistance of the voltmeter (very large)
- R = resistance to be measured



2) $V = I(R_a + R)$, $R = V - IR_{a,,}$, $R = V/I - R_a$

If R_a is very small ➔ $R = V/I$

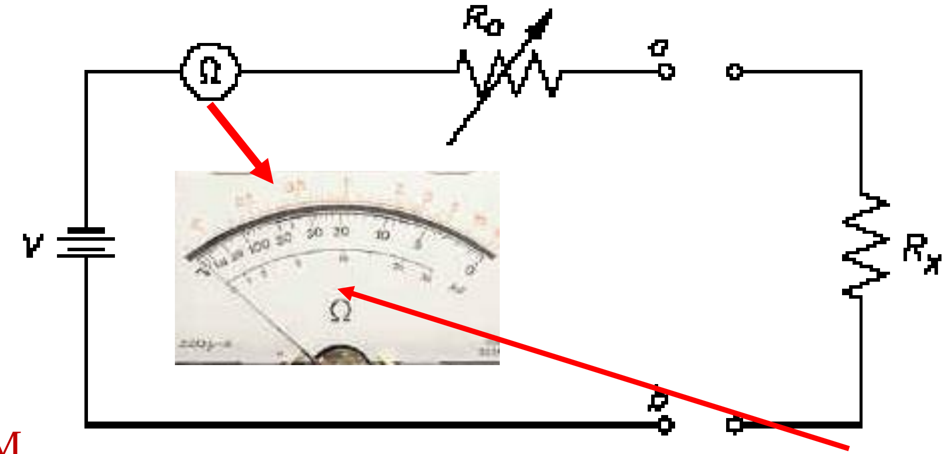
- R_a = resistance of the ammeter (very small)
- R_v = resistance of the voltmeter (very large)
- R = resistance to be measured



Resistance Measurement Technique

Ohmmeter: basic concept…

- uses a galvanometer to measure the electric current through the resistance
- R_O is an adjustable resistor to zero the meter & correct for aging battery (offset knob)
- R_O acts as current-limiter together with meter resistance, R_M
- Zero the ohmmeter by shorting a & b terminal & adjusting R_O to give full-scale deflection
- shorting a & b gives $I = V / (R_M + R_O)$
- includes R_X gives $I = V / (R_M + R_O + R_X)$



Movement of the moving coil is proportional to the amount of current flow

Resistance Measurement Technique

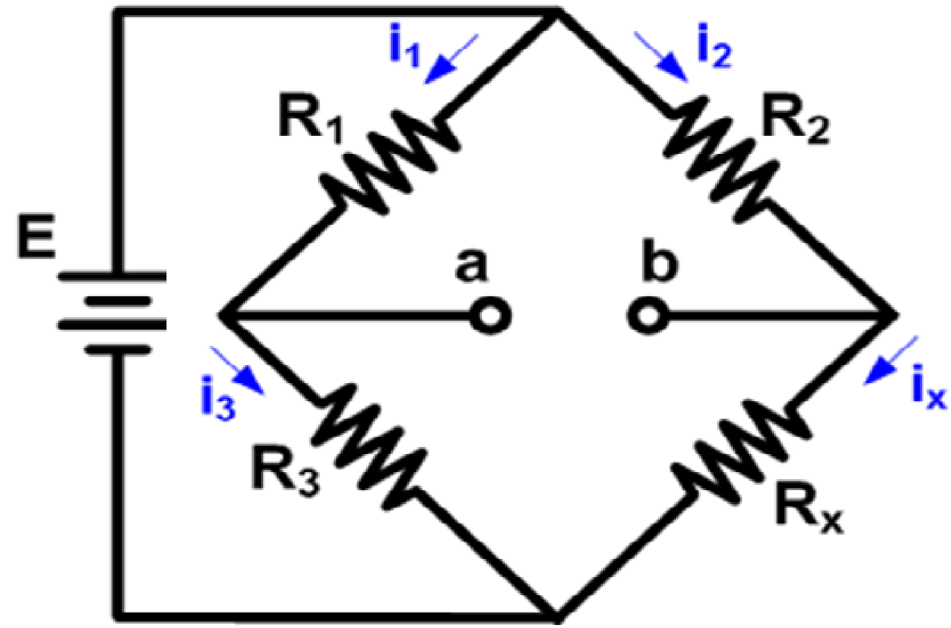
Ohmmeter: safety precautions

- the circuit is de-energized & discharged before connection
- switch "off" circuit while measuring resistance
- after using ohmmeter, switch to "off" position and disconnect leads
- always zero-ing before measurement

Resistance Measurement Technique

Wheatstone Bridge

- is a measuring instrument invented by Samuel Hunter Christie in 1833 and improv and popularized by Sir Char Wheatstone in 1843
- it is used to measure an unknown electrical resistance by balancing two legs of a bridge circuit, one leg of which includes the unknown component
- meter used is a sensitive galvanometer.

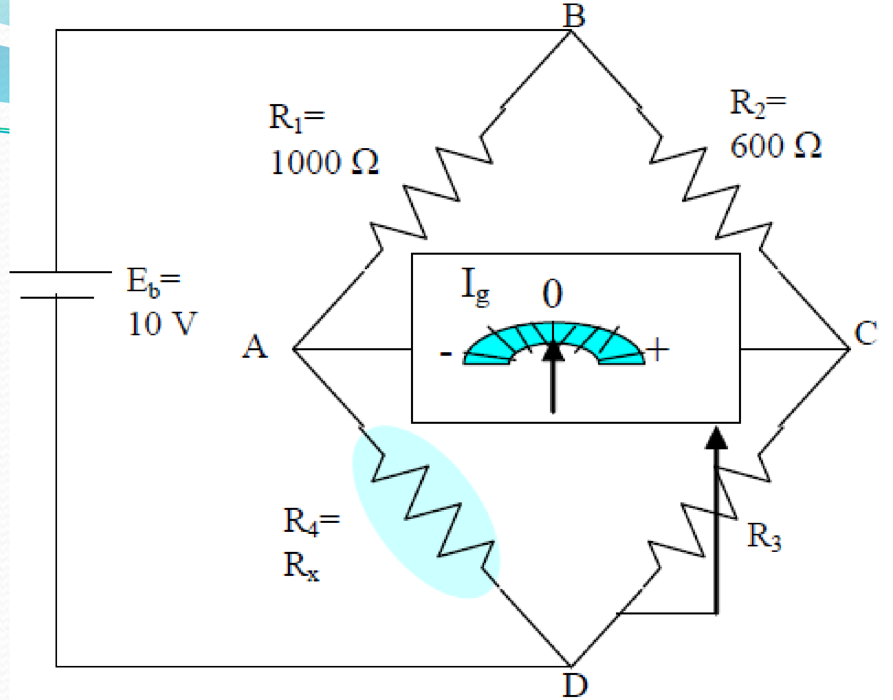


$$I_1 = I_3 = \frac{E}{R_1 + R_3}$$

$$I_2 = I_x = \frac{E}{R_2 + R_x}$$

$$\boxed{R_x = \frac{R_2 R_3}{R_1}}$$

Example 11



Assume that the Wheatstone bridge shown is used to determine the resistance of an unknown resistance *Rx*. The variable resistance is the resistance box that allows selection of several resistors in series to obtain the total resistance and it is set until null position in the meter observed. Calculate the unknown resistance if the variable resistance setting indicates 625.4Ω.

Solution

According to formula, the bridge will be balanced if

R1/R4 = R2/R3 . Hence, R4 =

Rx = R1/(R2/R3) = 1000 x 625.4 / 600 = 1042.3 Ω.

Capacitor Measurement Technique

Impedance, Z

- a measure of the overall opposition of a circuit to current.
- takes into account the effects of capacitance and inductance.
- capacitance& inductance cause a phase shift* between the I & V

Impedance, $\mathbf{Z} = \dfrac{\mathbf{V}}{\mathbf{I}}$

Resistance, $\mathbf{R} = \dfrac{\mathbf{V}}{\mathbf{I}}$

V = voltage in volts (V)
I = current in amps (A)
Z = impedance in ohms (Ω)

R = resistance in ohms (Ω)

Reactance, $X = X_L - X_c$

- **Capacitive reactance, Xc**

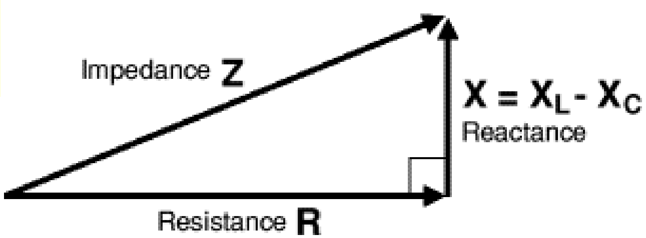
$$X_c = \frac{1}{2\pi fC}$$

where: Xc = reactance in ohms (Ω)
f = frequency in hertz (Hz)
C = capacitance in farads (F)

- **Inductive reactance, X_L**

$$X_L = 2\pi fL$$

where: X_L = reactance in ohms (Ω)
f = frequency in hertz (Hz)
L = inductance in henrys (H)



Impedance, $Z = \sqrt{R^2 + X^2}$

Capacitor Measurement Technique

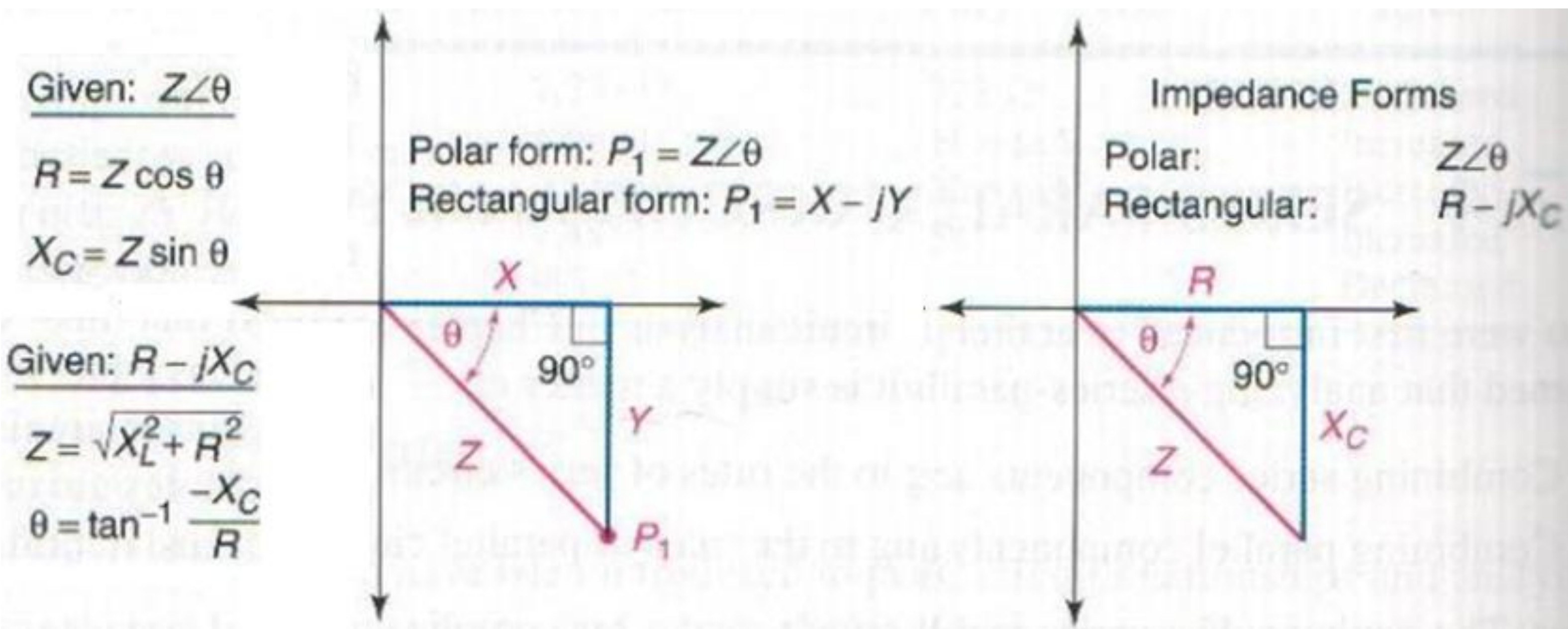
Impedance:

$$Z_1 + Z_2 = (R_1 + jX_1) + (R_2 + jX_2)$$
$$= (R_1 + R_2) + j(X_1 + X_2) = R_{eq} + jX_{eq}$$

magnitude

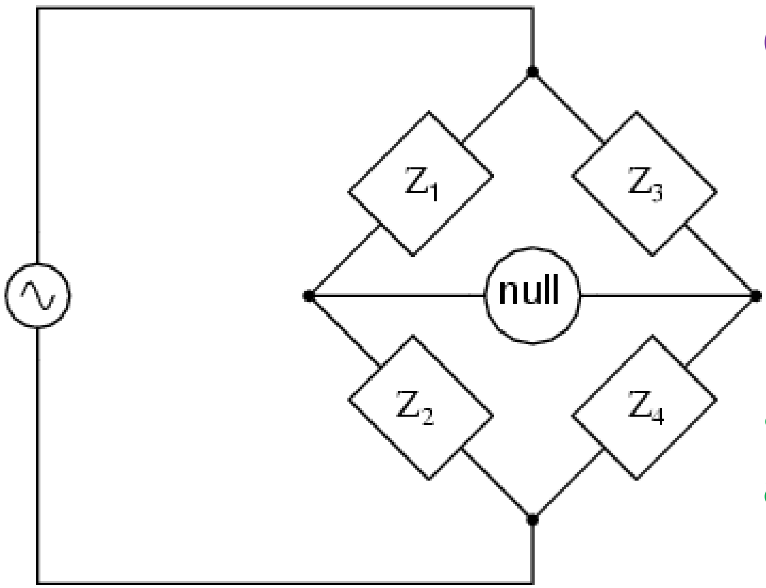
$$|Z| = \sqrt{R_{eq}^2 + X_{eq}^2} \qquad \phi = \tan^{-1}\frac{X_{eq}}{R_{eq}}$$

phase



Capacitor Measurement Technique

AC bridge: (all ac bridge circuits based on Wheatstone bridge)



- for this general form of AC bridge to balance, the impedance ratios of each branch must be equal:

$$\frac{Z_1}{Z_2} = \frac{Z_3}{Z_4}$$

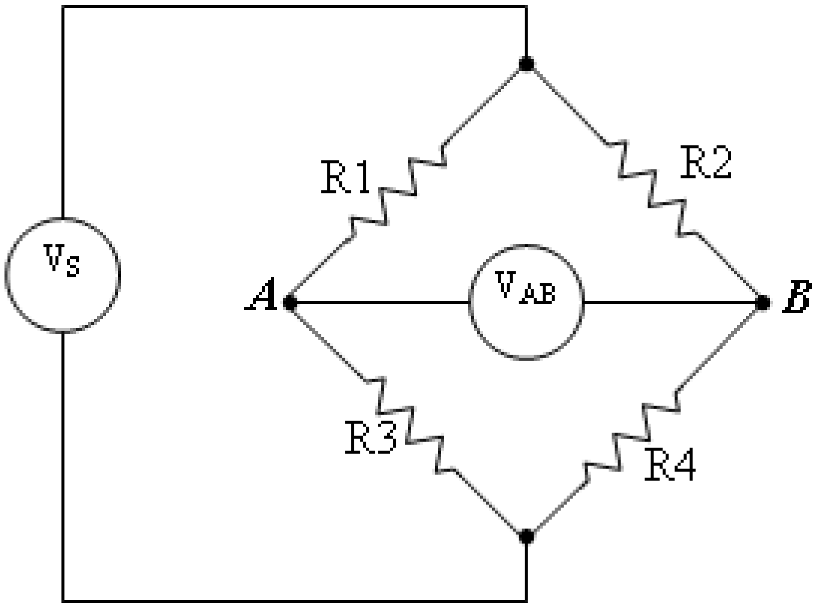
- impedance quantities *must* be complex, accounting for both magnitude and phase angle

- It is insufficient that the impedance magnitudes alone be balanced

Capacitor Measurement Technique

AC bridge: Wheatstone bridge

Theory



Wheatstone's Bridge

- A null reading is obtained on a Wheatstone bridge by a comparison of the voltage drops in the passive resistance arms of the bridge

- When the equation *R1R4 = R2R3* , the bridge is balanced and a “null” or zero reading is obtained on the detector

- The voltage at the nodes *A* and *B* may be computed using the simple potential division rule as below:

Capacitor Measurement Technique

AC bridge: Wheatstone bridge Theory cont….

Consider the Wheatstone's bridge shown in Fig. 1.1. It has four arms each having a resistance. The voltage at the nodes ***A*** and ***B*** may be computed using the simple potential division rule as below:

$$V_A = \frac{R_3}{R_1 + R_3}.V_S \qquad (1.1)$$

$$V_B = \frac{R_4}{R_2 + R_4}V_S \qquad (1.2)$$

The voltage across the nodes ***A*** and ***B*** measured in the voltmeter would equal the difference between the voltages at nodes ***A*** and ***B***:

$$V_{AB} = V_A - V_B = \frac{R_3}{R_1 + R_3}V_S - \frac{R_4}{R_2 + R_4}V_S \qquad (1.3)$$

Capacitor Measurement Technique

AC bridge: Wheatstone bridge

Theory cont.…

When the Wheatstone's bridge is balanced, the voltage V_{AB} would equal zero. Thus in that condition, equating V_{AB} to zero in equation (1.3), one gets:

$$V_{AB} = \frac{R_3}{R_1 + R_3} V_S - \frac{R_4}{R_2 + R_4} V_S = 0 \qquad (1.4)$$

On re-arranging, one gets: $\frac{R_3}{R_1 + R_3} = \frac{R_4}{R_2 + R_4}$.

(1.5)

Thus one may derive:

$$R_1 R_4 = R_2 R_3 \qquad (1.6)$$

Capacitor Measurement Technique

AC bridge: Example 12,

The impedances of the ac bridge in Figure 4.11 are given as follows:

$$Z_1 = 200\ \Omega\angle 30^o$$
$$Z_2 = 150\ \Omega\angle 0^o$$
$$Z_3 = 250\ \Omega\angle -40^o$$
$$Z_x = Z_4 = unknown$$

Determine the constants of the unknown arm.

Solution:

The first condition for bridge balance requires that

$$Z_1 Z_x = Z_2 Z_3$$

or

$$Z_x = \frac{Z_2 Z_3}{Z_1} = \frac{150\Omega \times 250\Omega}{200\Omega} = 187.5\Omega$$

Capacitor Measurement Technique

AC bridge: Example 13,

The second condition for balance requires that the sums of the phase angles of opposite arms be equal.

$$\theta_1 + \theta_x = \theta_2 + \theta_3$$

or

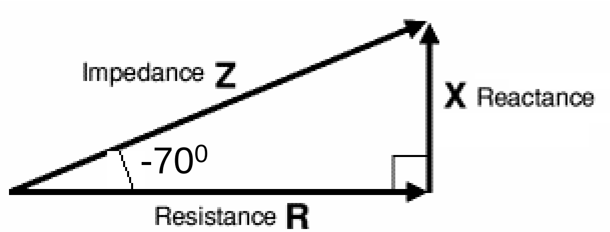
$$\theta_x = \theta_2 + \theta_3 - \theta_1$$
$$= 0^\circ + (-40^\circ) - 30^\circ = -70^\circ$$

Hence, the unknown impedances Z_x can be written as,

$$Z_x = 187.5\,\Omega \angle{-70^\circ} = (64.13 - j176.19)\,\Omega$$

- Polar form - Rectangular form

indicating that we are dealing with capacitive element, possibly consisting of series resistor and a capacitor.

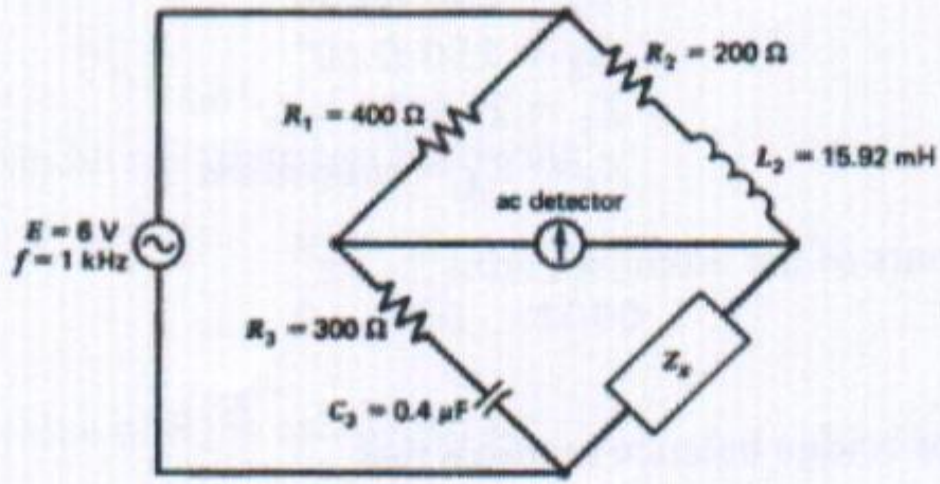


$Z_X = 187.5 \cos(-70^0) - j187.5 \sin(-70^0)$
$= (64.13 - j176.19)$ ohm (rectangular)

Capacitor Measurement Technique

AC bridge: Example 14,

Given the ac bridge in Figure 4.13 below, find the components of the unknown arm Z_x.



Ac bridge in balance

Solution:

$$\omega = 2\pi f = 2 \times \pi \times 1000Hz = 6283.19\ rad/sec$$

$$X_{L2} = \omega L_2 = 6283.19 \times 15.92 \times 10^{-3} = 100\Omega$$

$$X_{C3} = \frac{1}{\omega C_3} = \frac{1}{6283.19 \times 0.4 \times 10^{-6}}$$

Capacitor Measurement Technique

AC bridge: Example 13 Cont.,

The impedances of the bridge arms are

$$Z_1 = R_1 = 400\ \Omega\angle 0^\circ$$
$$Z_2 = R_2 + jX_{L2} = 200 + j100 = 223.6\angle 26.6^\circ$$
$$Z_3 = R_3 - jX_{C3} = 300 - j400 = 500\angle -53^\circ$$
$$Z_x = \frac{Z_2 Z_3}{Z_1} = \frac{(223.6\angle 26.6^\circ)(500\angle -53^\circ)}{400\angle 0^\circ} = 279.5\Omega\angle -26.4^\circ$$
$$= (250.35 - j124.28)\Omega$$

Therefore,

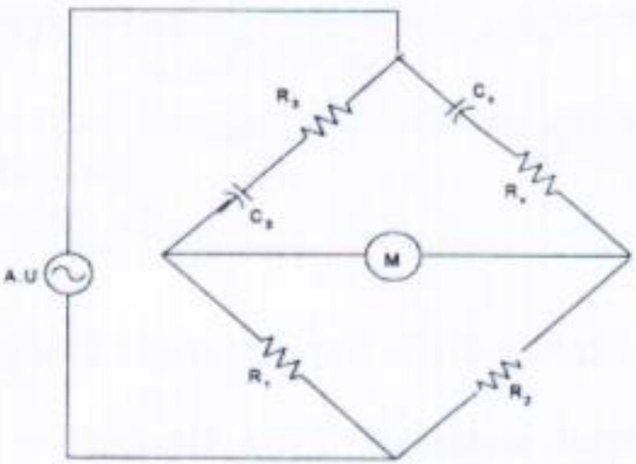
$$C = \frac{1}{\omega X_C} = \frac{1}{6283.19 \times 124.28} = 1.28\mu F$$

Thus, the equivalent-series resistances is 250.35Ω, and the equivalent capacitances is $1.28\mu F$

Capacitor Measurement Technique

Serial-capacitor type bridge:

Figure shows a serial-capacitor type Bridge.



Serial-capacitor type Bridge

Arm 1: $Z_1 = R_3 - j\left(\frac{1}{wC_3}\right)$

Arm 2: $Z_2 = R_x - j\left(\frac{1}{wC_x}\right)$

Arm 3: $Z_3 = R_1$ Arm 4: $Z_4 = R_2$

From the balanced equation $Z_1Z_4 = Z_2Z_3$ we get

$$\left[R_3 - j\left(\frac{1}{wC_3}\right)\right] R_2 = \left[R_x - j\left(\frac{1}{wC_x}\right)\right] R_1$$

$$R_2R_3 - j\left(\frac{R_2}{wC_3}\right) = R_1R_x - j\left(\frac{R_1}{wC_x}\right)$$

Right = left

Real part : $R_2R_3 = R_1R_x$ so that $R_x = \frac{R_2R_3}{R_1}$

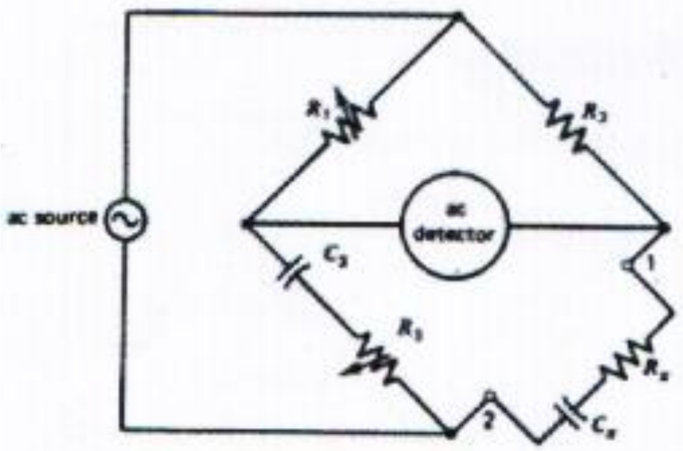
Imaginary part : $j\left(\frac{R_2}{wC_3}\right) = j\left(\frac{R_1}{wC_x}\right)$

$$R_2wC_x = R_1wC_3$$

$$C_x = \frac{R_1C_3}{R_2}$$

Capacitor Measurement Technique

Serial-capacitor type bridge: Example 14



Similar-angle Bridge

A similar angle bridge (serial capacitor Type Bridge) is used to measure capacitive impedances at a frequency of 2 kHz. The bridge constants at balance are:

$$C_3 = 100\mu F, \quad R_1 = 10k\Omega$$
$$R_2 = 50k\Omega, \quad R_3 = 100k\Omega$$

Find the equivalent-series circuit of the unknown impedance.

Solution:

Find R_x:

$$R_x = \frac{R_2}{R_1} R_3 = \frac{(50 \times 10^3\Omega)(100 \times 10^3\Omega)}{10 \times 10^3\Omega} = 500k\Omega$$

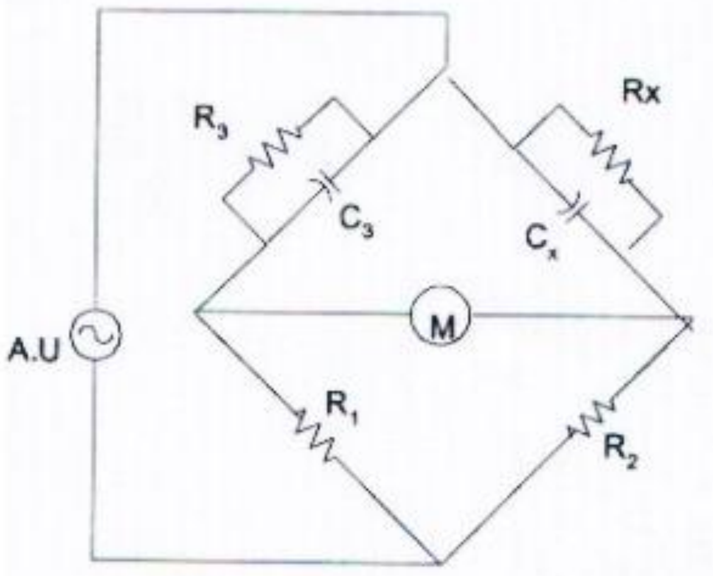
Then, find C_x:

$$C_x = \frac{R_1}{R_2} C_3 = \frac{(10 \times 10^3\Omega)(100 \times 10^{-6}F)}{50 \times 10^3\Omega} = 20\mu F$$

Capacitor Measurement Technique

Parallel-capacitor type bridge:

Figure shows a parallel-capacitor type Bridge.



Parallel-capacitor type Bridge

We will get the resistance and capacitance value from this equation by using a balanced concept.

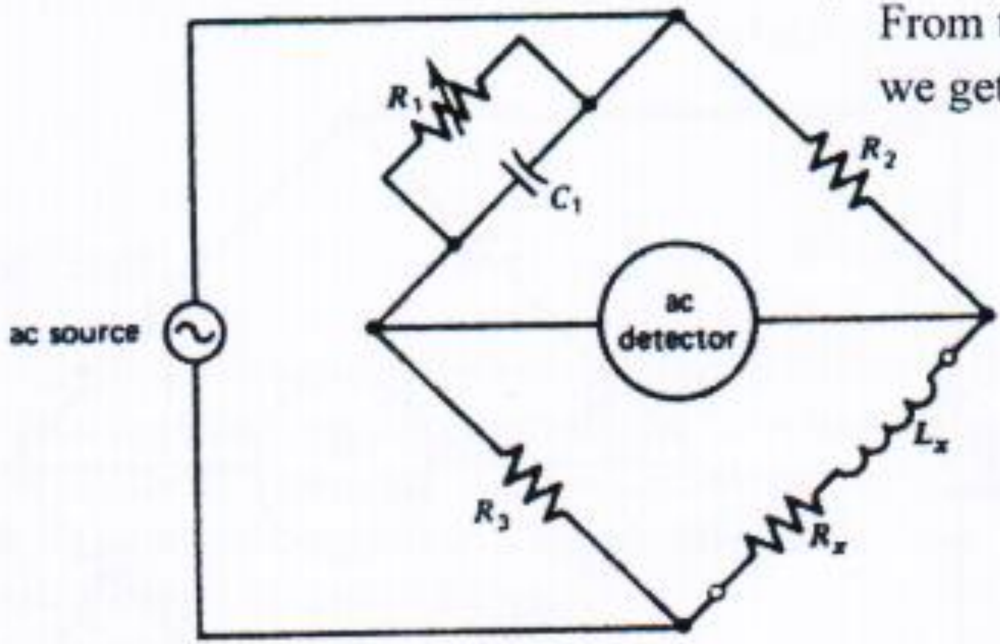
$$R_x = \frac{R_1 R_3}{R_2} \quad \text{and} \quad C_x = \frac{C_1 R_2}{R_3}$$

Inductor Measurement Techniques

Maxwell bridge: (1 < Q < 10)

Q, ratio of coil reactance to a-c resistance

Figure shows the Maxwell Bridge. It can measure high power dissipation (low Q). The range is between 1uH to 1 kHz with accuracy 2%.



Maxwell Bridge

From the balanced condition, $Z_1Z_4 = Z_2Z_3$, we get

$$R_x = \frac{R_2R_3}{R_1} \quad \text{and} \quad Lx = R_2R_3C_1$$

Maxwell bridge: Example 15

A Maxwell bridge as in Figure 4.13 is used to measure inductive impedance. The bridge constants at balance are:

$$C_1 = 0.01\mu F, \qquad R_1 = 470k\Omega$$
$$R_2 = 5.1k\Omega, \qquad R_3 = 100k\Omega$$

Find the series-equivalent resistances and inductance.

Solution:

Find R_x and L_x:

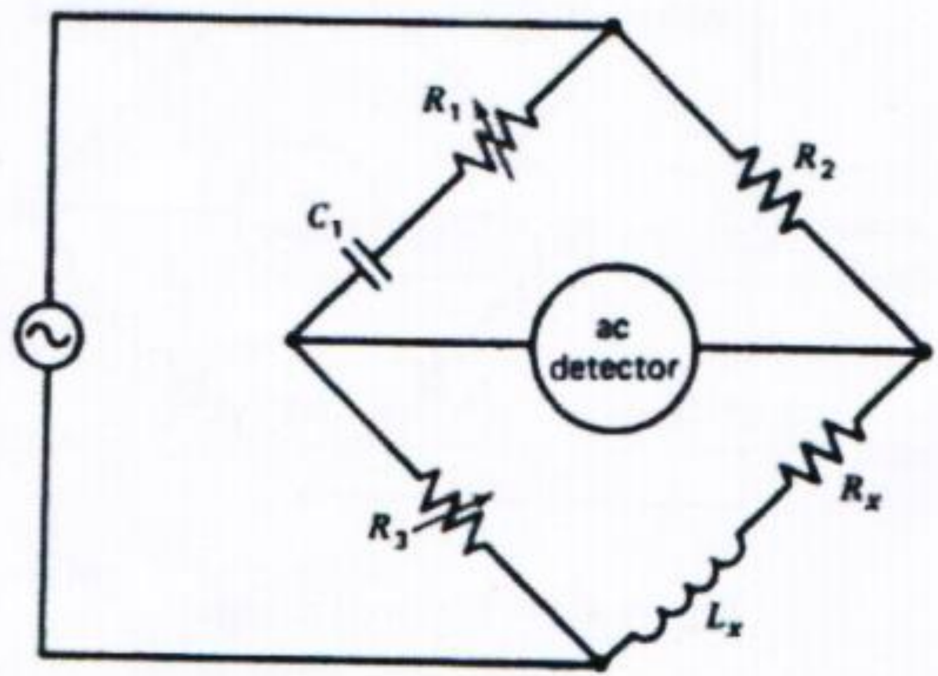
$$R_x = \frac{R_2 R_3}{R_1} = \frac{(5.1\times 10^3\Omega)(100\times 10^3\Omega)}{470\times 10^3\Omega} = 1.09k\Omega$$

$$L_x = R_2 R_3 C_1 = (5.1\times 10^3)(100\times 10^3)(0.01\times 10^{-6}) = 5.1H$$

Inductor Measurement Techniques

Hay bridge: (10 < Q < 1000), Example 16

Figure shows the Hay Bridge.



The value of R and L can be obtained from this equation

$$R_x = \frac{w^2 R_1 R_2 R_3 C_1^{\,2}}{1 + w^2 R_1^{\,2} C_1^{\,2}} \quad \text{and} \quad L_x = \frac{R_2 R_3 C_1}{1 + w^2 R_1^{\,2} C_1^{\,2}}$$

Inductor Measurement Techniques

Hay bridge: (10 < Q < 1000) Example 17

Find the series-equivalent inductance and resistance of the network that causes an opposite-angle bridge (Hay Bridge) to null with the following components values:

$$\omega = \frac{3000\ rad}{s}, \qquad R_2 = 10k\Omega,$$
$$R_1 = 2k\Omega, \qquad R_3 = 1k\Omega, \qquad C_1 = 1\mu F$$

Solution:

Find R_x and L_x:

$$R_x = \frac{\omega^2 R_1 R_2 R_3 C_1^2}{1 + \omega^2 R_1^2 C_1^2}$$

$$R_x = \frac{(3\times10^3)^2(2\times10^3)(10\times10^3)(1\times10^{-6})^2}{1+(3\times10^3)^2(2\times10^3)^2(1\times10^{-6})^2} = \frac{180\times10^3}{1+36} = 4.86k\Omega$$

$$L_x = \frac{R_2 R_3 C_1}{1+\omega^2 R_1^2 C_1^2}$$

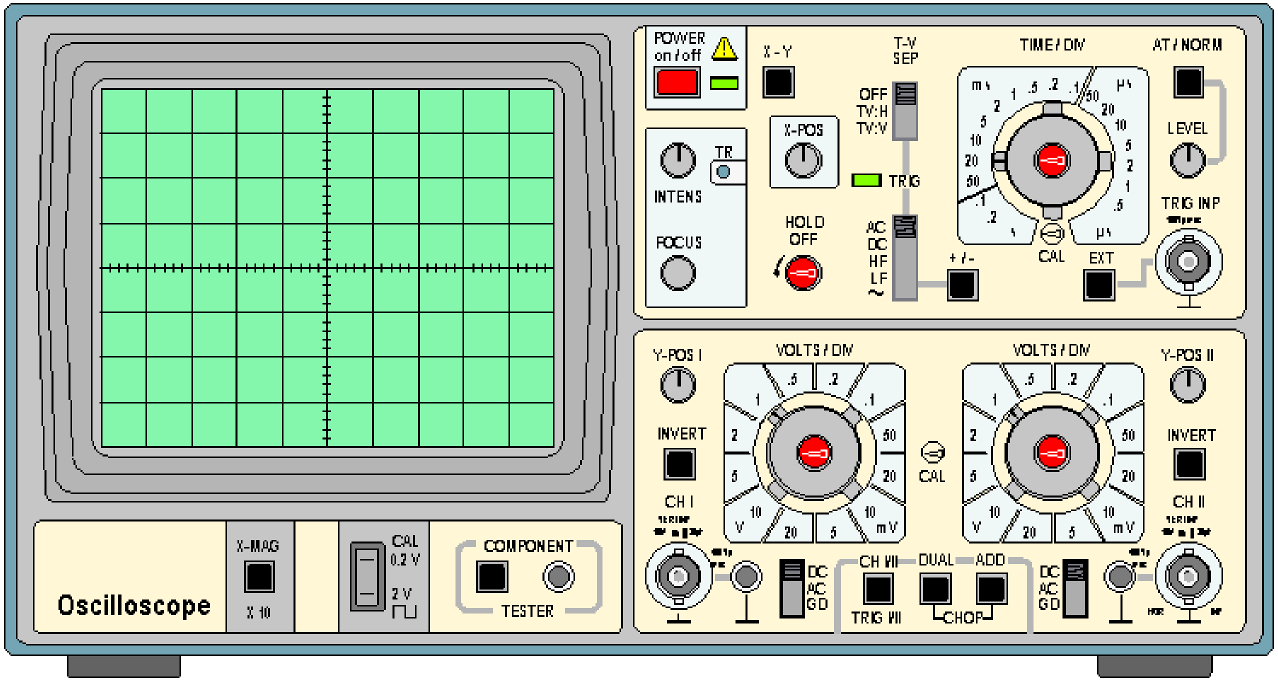
$$= \frac{(10\times10^3)(1\times10^3)(1\times10^{-6})}{1+(3\times10^3)^2(2\times10^3)^2(1\times10^{-6})^2} = \frac{10}{1+36} = 0.27 = 270mH$$

Oscilloscope / CRO

Introduction:

- oscilloscope is basically a graph-displaying device - it draws a graph of an electrical signal

- In most applications the graph shows how signals change over time

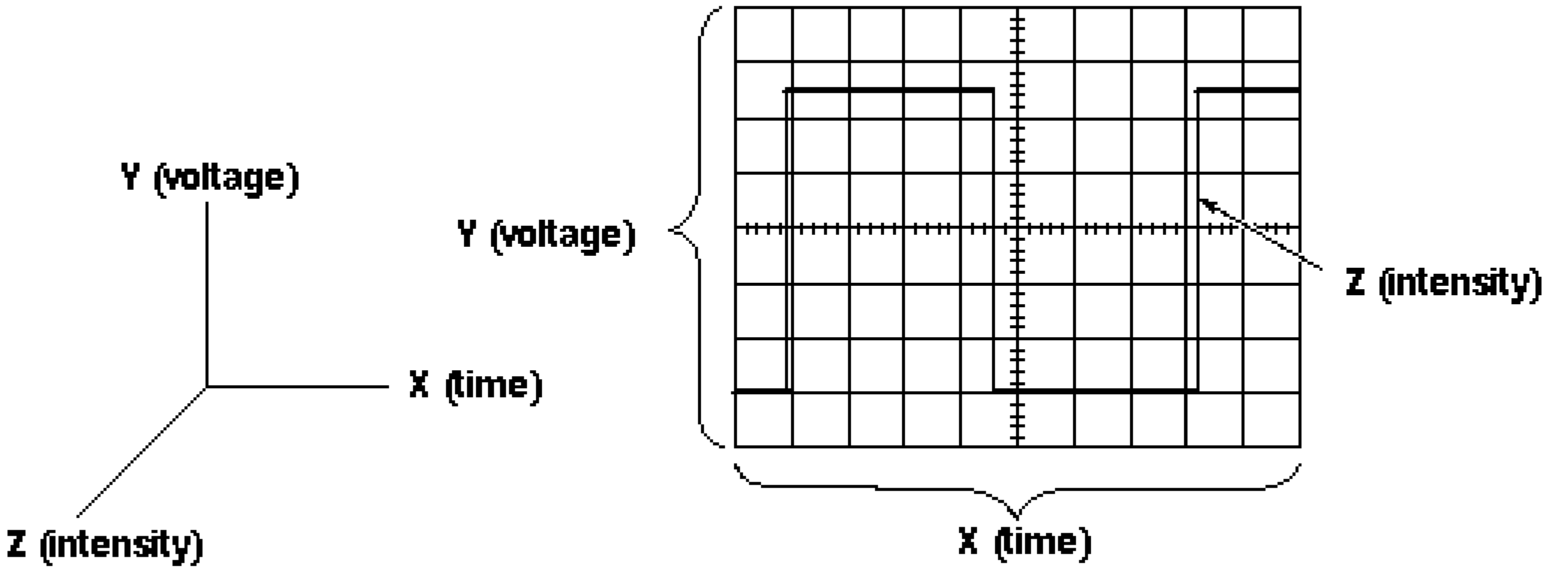


Oscilloscope

Introduction:

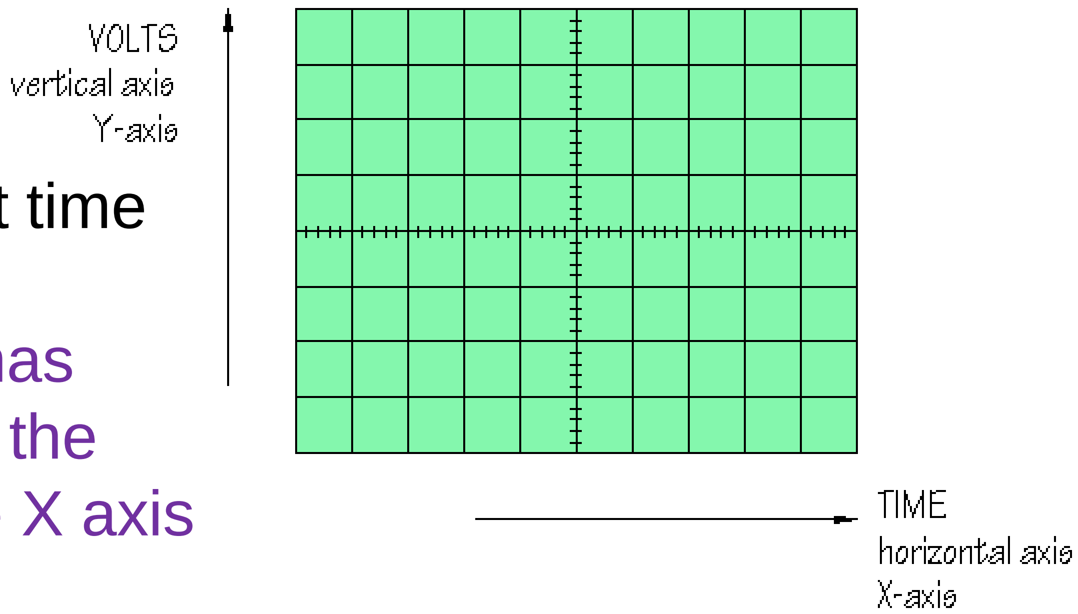
- the vertical (Y) axis represents voltage and the horizontal (X) axis represents time.

- The intensity or brightness of the display is sometimes called the Z axis



Oscilloscope

Introduction:



- oscilloscope draws a *V/t* graph, voltage against time

- screen of oscilloscope has 8 squares or divisions on the Y axis, 10 squares on the X axis (~1cm in each direction)

- can change the Y or X axis, so that you can display a clear picture of the signal you want to investigate

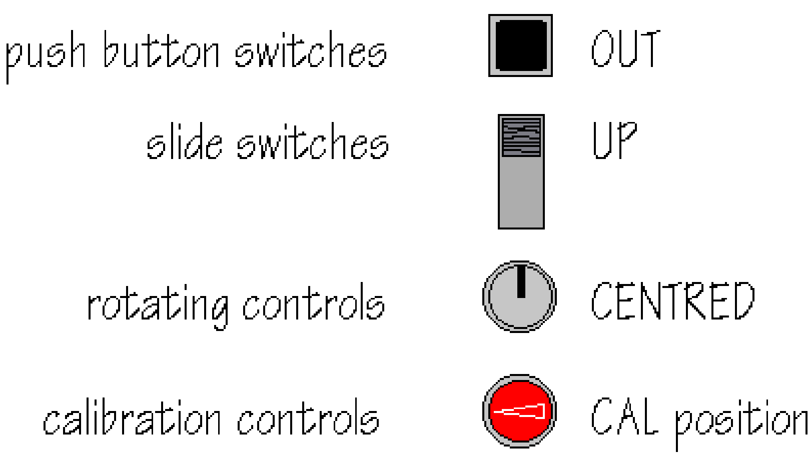
- 'Dual trace' oscilloscopes display two *V/t* graphs at the same time, so that simultaneous signals from different parts of an electronic system can be compared.

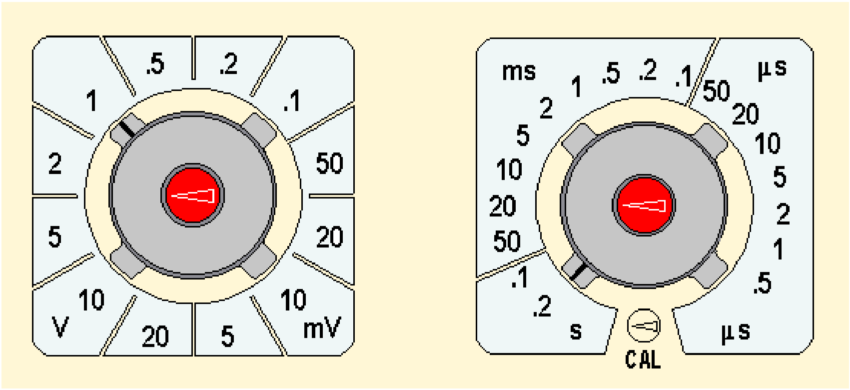
Oscilloscope

Procedure:

• Before turning ‘ON’ oscilloscope., check that all the controls in their 'normal' positions:

- push button switches in the OUT position
- slide switches in the UP position
- rotating controls are CENTRED
- the central TIME/DIV and VOLTS/DIV and the HOLD OFF controls are in the calibrated, or CAL position
- Set both VOLTS/DIV controls to 1 V/DIV and the TIME/DIV control to 2 s/DIV, its slowest setting:

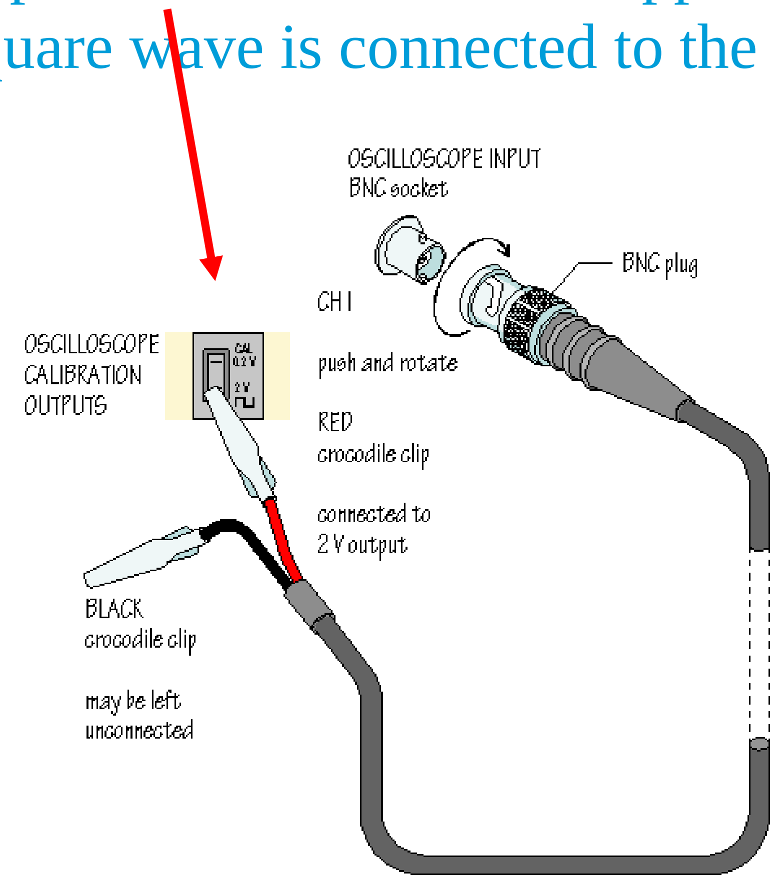


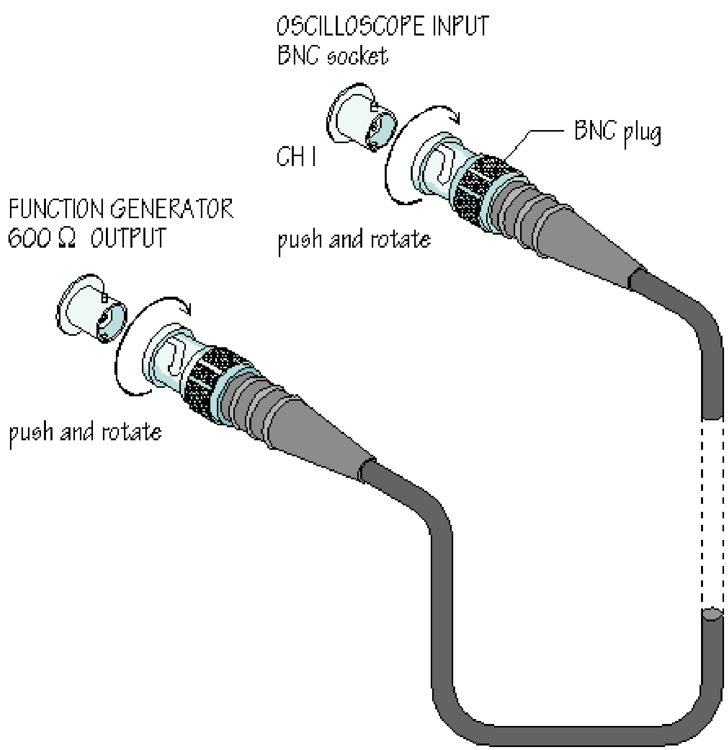


Oscilloscope

Cables:

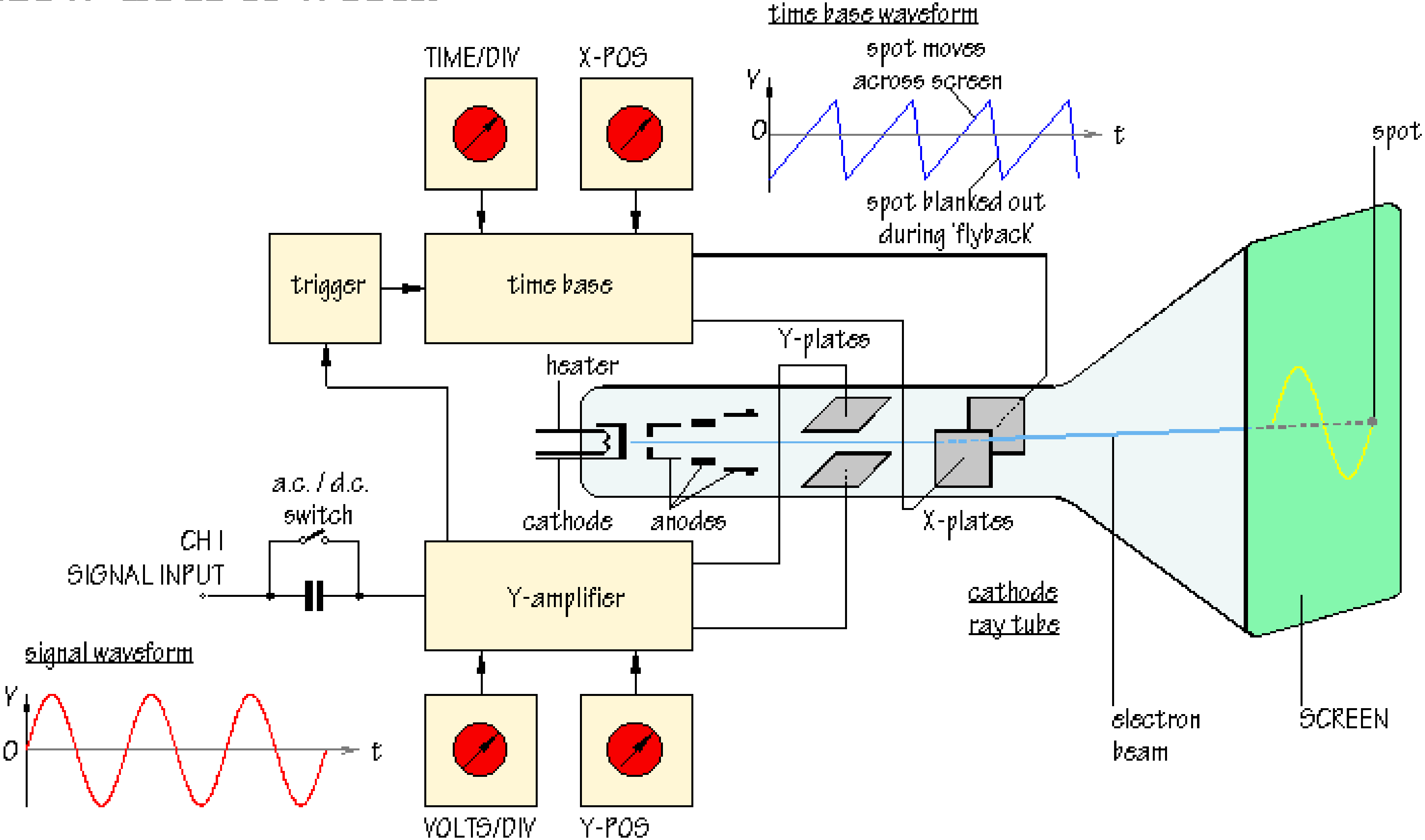
The diagram shows a lead with a (Bayonet Neill-Concelman) BNC plug at one end and crocodile clips at the other. When the crocodile clip from the red wire is clipped to the lower metal terminal, a 2 V square wave is connected to the input of CH 1.





Oscilloscope

How does it work:

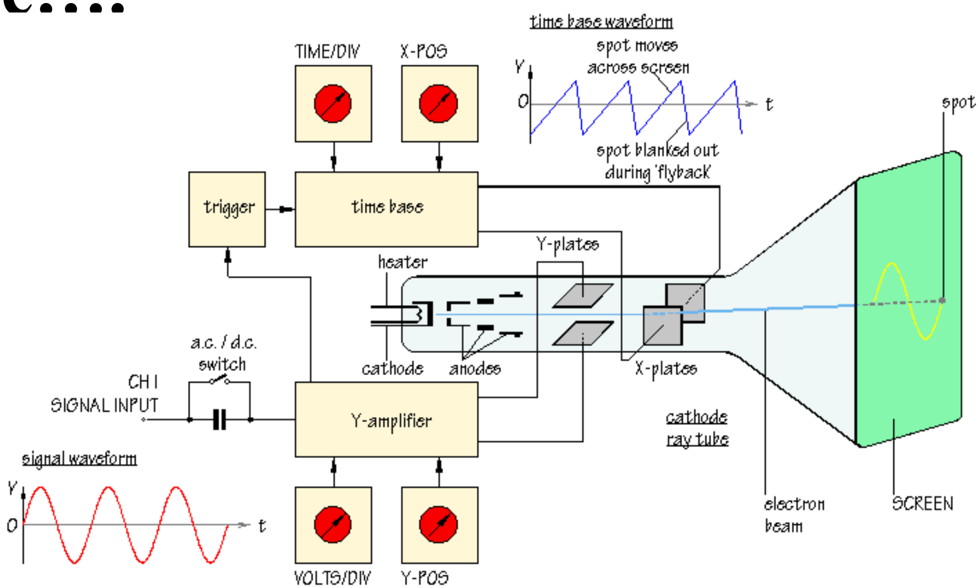


Oscilloscope

How does it work: continue….

- the screen of an oscilloscope consists of a cathode ray tube, similar principles to TV

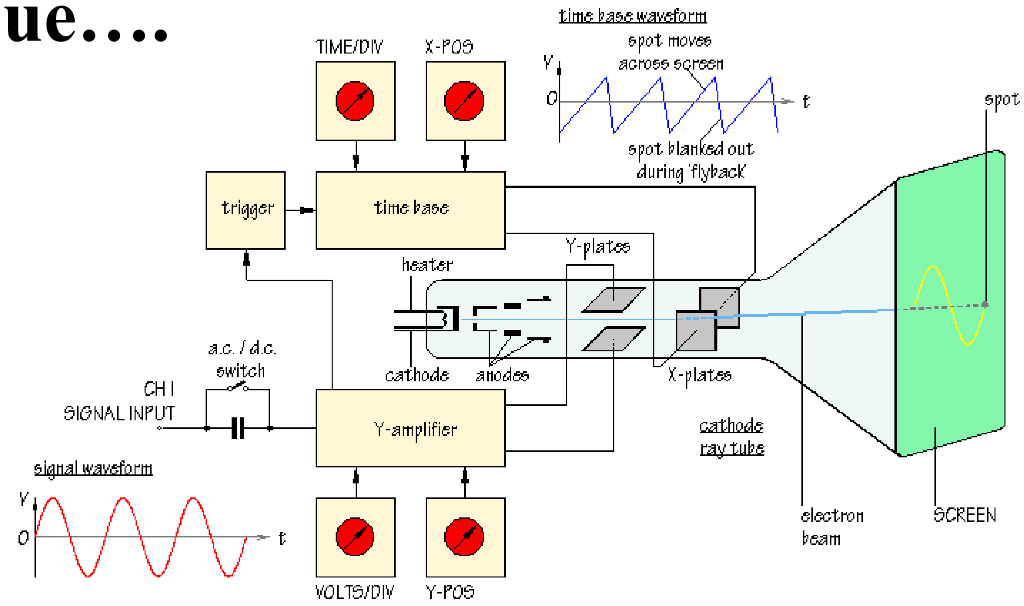
- Inside the tube is a vacuum.



•The electron beam emitted by the heated cathode at the rear end of the tube is accelerated and focused by one or more anodes, and strikes the front of the tube, producing a bright spot on the phosphorescent screen.

Oscilloscope

How does it work: continue….



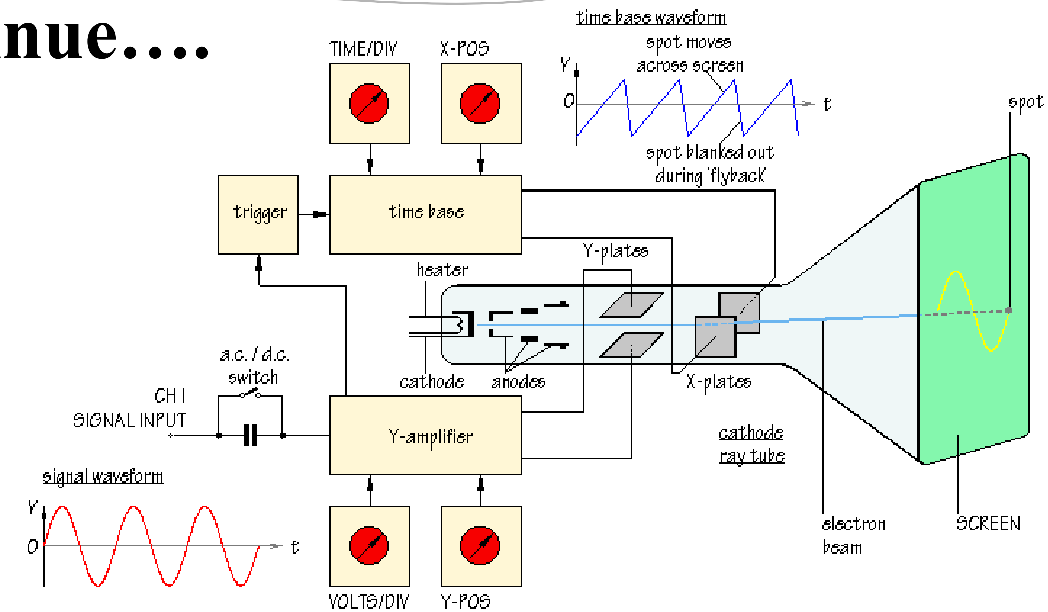
- The electron beam is bent, or deflected, by voltages applied to two sets of plates fixed in the tube

- The horizontal deflection plates, or X-plates produce side to side movement

- As you can see, they are linked to a system block called the time base

Oscilloscope

How does it work: continue….



- This produces a sawtooth Waveform

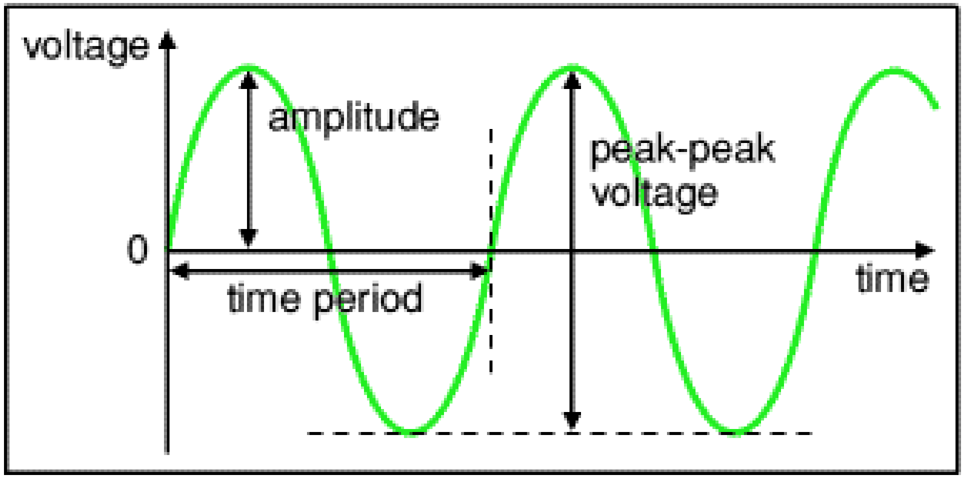
- During the rising phase of the sawtooth, the spot is driven at a uniform rate from left to right across the front of the screen

- During the falling phase, the electron beam returns rapidly from right to left, but the spot is 'blanked out' so that nothing appears on the screen

- In this way, the time base generates the X-axis of the *V*/*t* graph

Oscilloscope

Waveform measurement



- The trace on an oscilloscope screen is a graph of voltage against time

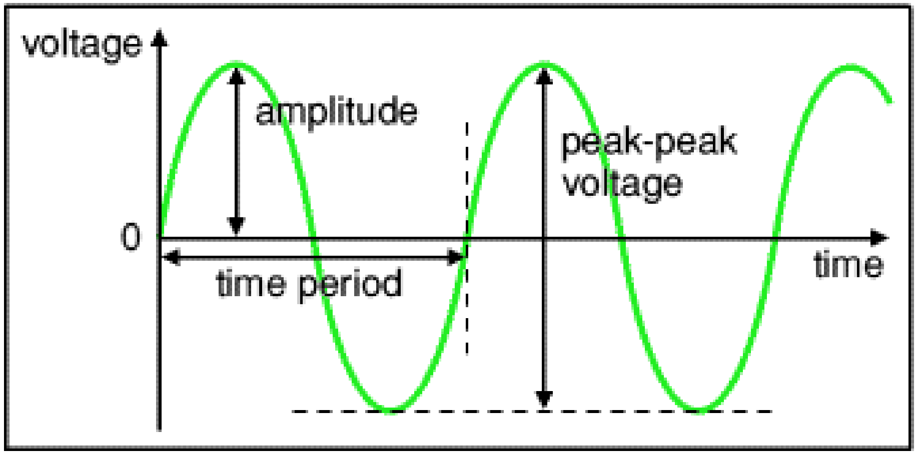
- The shape of this graph is determined by the nature of the input signal.

•In addition to the properties labelled on the graph, there is frequency which is the number of cycles per second

•The diagram shows a sine wave

Oscilloscope

Waveform measurement cont….



• Amplitude or peak voltage is the max. voltage reached by the signal, measured in volts, V

• Peak-peak voltage is twice the peak voltage (amplitude)

• Time period is the time taken for the signal to complete one cycle, measured in seconds

• Frequency is the number of cycles per second, measured in hertz (Hz

Waveform measurement: Example 18

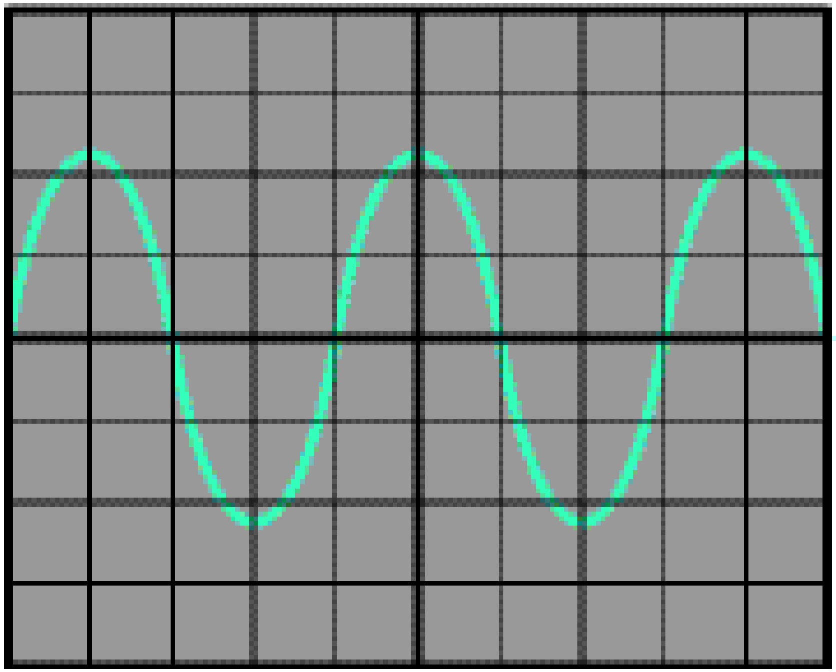
Example measurements:

peak-peak voltage = 8.4V

amplitude voltage = 4.2V

time period = 20ms

frequency = 50Hz



The trace of an AC signal

Y AMPLIFIER/CHANNEL: 2V/cm
TIMEBASE: 5ms/cm